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A paper to be presented at the 14th General Meeting of the American Institute of Electrical Engineer, Eliot, Me., July 27th, 1897.

[ADVANCE COPY—SUBJECT TO REVISION.]

THE EFFECT OF ARMATURE INDUCTANCE UPON THE ELECTROMOTIVE FORCE CURVES OF AN ALTERNATOR.

BY W. E. GOLDSBOROUGH.

The subject of the regulation of alternating dynamo-electric machines, considered as a function of the inductance of their armature coils, has been treated by a number of writers, and during the last few years has attracted much attention.

In looking up the bibliography of the subject, however, I find that but few records have been published of the actual value of the inductance of the generating coils of these machines, and that even less data are available regarding the real nature of the periodic fluctuations that take place in this quantity.

We are indebted to Hopkinson, Ayrton, Kapp, Sumpner, Duncan, Tobey and Walbridge, Reid, Steinmetz, Fleming, Rothert, Roessler and many others for much valuable information touching upon the theory and practice of the design and handling of machines of this type, but these writers, in-so-far as I am informed, have failed to furnish us with a record of the actual internal relations existing between the factors involved, freed of conventional and restricting assumptions.

With the assistance of Mr. W. N. Motter and Mr. S. R. Fox, I have carried on a series of experiments in the electrical laboratories of Purdue University for the purpose of investigating the subject.

Apparatus and Method Employed.

The experiments which I shall describe were made upon a three-light Brush arc machine, fitted with the necessary exploring coils, collector rings and revolving contact-making device. The

machine was selected on account of the peculiarities of its design. These were particularly valuable, as the end sought was to obtain results of an exaggerated nature in order that the factors entering into the problem could be brought into bold relief and thereby lend themselves to more ready investigation.

The core of the armature is of the ring type and is built up of laminated iron stampings, held together by laminated iron bands passing around the core between the successive layers of stampings. Each stamping, therefore, forms a portion of the surface of a cylinder having its axis coincident with the axis of rotation. The stampings are shaped so as to make sixteen large teeth of trapezoidal section, which project laterally from the core,

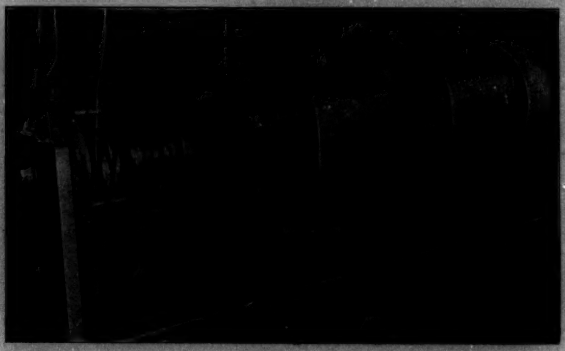


FIG. 1.

there being eight on each side. The armature winding is composed of eight coils or bobbins of 286 turns each. The bobbins on opposite sides of the armature are connected in series, and their free ends brought out to one pair of the eight commutator segments. Previous to making the experiments, all of the copper commutator segments were removed, and two cast-iron collector rings substituted for them. Fig. 1 shows the machine with these in position, and the collecting brushes in place. Each ring was connected electrically to one of a pair of commutator segment terminals, to which the free ends of one pair of the armature bobbins were fastened. The rings were then carefully insulated from contact with all the other commutator terminals. As the

armature is of the open coil type, each commutator segment is attached to the terminal of but one coil, and therefore, by the arrangement described, the arc machine was converted into a two-coil alternator. Throughout the test, the remaining six coils were practically dead, being cut out and left on open circuit.

Owing to the fact that the armature bobbins are wound between large projecting teeth, and since the clearance spaces between the teeth and the pole faces are relatively small, the inductance of the coils is high. The coils are practically buried in iron, and the leakage of the magnetic lines of force set up in them is slight. There are in all, 16 teeth on the armature core, or 4 to each pole face. As the armature revolves, there are alternatively 3 and then 4 teeth opposite each pole face. The latter condition occurs when two of the coils take up positions midway between the pole corners, as for instance, coils 1 and 2 in Fig. 2. The former when four of the teeth reach positions midway between the pole corners N, S, and N', S'. The reluctance of the path of the magnetic flux through the field frame and the armature core is therefore a variable quantity, and pulsates between its maximum and minimum values eight times during each revolution of the armature.

The four field exciting coils are connected in series in such a way as to form like magnetic poles facing one another, on the same side of the armature shaft. By this arrangement the lines of force entering the armature core from abutting pole-pieces repel one another and, dividing, penetrate the armature core above and below the shaft in a direction perpendicular to a vertical plane passed through the centre of rotation and parallel to the shaft. When the armature core is at rest, therefore, and the field coils separately excited, the field flux passing through any pair of armature coils will be a maximum when they are in positions 1, 2, Fig. 2, and will be zero when they are in positions 5, 6.

The method employed in making determinations of the self-induction of the armature was as follows:

An exploring coil of 42 turns of No. 36 B & S copper wire was wound over armature coil 1, and connected in series with the field coils of a high-resistance Nalder ballistic galvanometer and an adjustable non-inductive resistance. A constant exciting current of 10 amperes was kept flowing through the field circuit at all times. During the time of taking any one set of readings,

a direct current of definite value was maintained in coils 1 and 2 except when the deflections were made. In circuit with the two armature coils and the source of power, were connected a Weston ammeter, the primary of the calibrating coil of the ballistic galvanometer and a snap switch. The snap switch being actuated by a spring, gave exactly the same form of mechanical "make" and "break" of the current at each reading. Readings were taken when making and when breaking the current in the armature coils, and the average of four observations made a record for a given angular position of the coils.

The angular position of the coils relative to the poles was indicated by the graduated disk of the contact-making device by

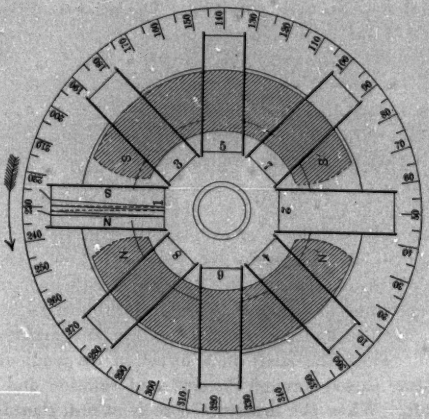


FIG. 2.—Showing coils No. 1 and 2 at "Zero Position" between the Pole Tips N, S, and N', S'.

adjusting it relatively to a point on the contact wheel at the time of taking each reading. Knowing the deflections of the galvanometer and having complete data covering the calibration of the instrument and the construction of the armature, the inductance of the coils at any given point was very readily calculated.

In determining the form of the electromotive force waves induced in the coils and appearing at the brushes of the machine, a form of contact-making device shown in Fig. 1 was used in connection with an improvised form of electro-dynamometer. The contact-making device possesses no new features. The

galvanometer is of the Wiedemann type. The bell-shaped magnet and copper damper were removed from the instrument and in place of these a wooden ball carrying a coil of fine wire imbedded in a deep narrow groove cut into its surface was substituted. Two pieces of copper wire were mounted upon the ball or needle in the plane of the coil, and at the extremities of a diameter to form an axis of rotation. The upper end of this axis made one terminal of the coil, it carried a small plane mirror and was connected at its extremity to a piece of hard-drawn brass wire. This wire being also attached to the torsion head, both sustained the weight of the ball and balanced by its torsion the deflecting force of the current impulses passed through the needle. The lower end of the axis formed the other terminal of the coil and carried a small paddle. It dipped into a cup containing mercury and glycerine: the glycerine sufficing to dampen the needle and the mercury making electric contact with it. When in use, the field coils of the galvanometer were excited with a constant current. The ball or needle was connected directly in series with the rotary contact, and with from two to three incandescent lamps, according to the value of voltage to be measured. The instrument was calibrated by connecting a constant current machine in series with the needle, lamps and rotary contact, and comparing the deflections of the needle taken while the contact was rotating at normal speed, with the readings of a voltmeter connected to the terminals of the source of constant E. M. F. During all the experiments the galvanometer gave deflections as constant and as dead beat as those of a Weston ammeter. The arrangement of this apparatus is analogous to that described by Duncan[1] in 1892.

Armature Inductance.

In determining the coefficient of self-induction of coils 1 and 2, coil 1 of the armature was placed at the 230° position, as indicated in Fig. 2, since at this point the magnetizing power of the coils was least, owing to the large magnetic reluctance of the circuit traversed by the lines of force emanating from the coils. The high reluctance is due to the fact that the iron of the core surrounded by the coils, and the iron of the pole tips N, N′ and S, S′, is all highly saturated by the field flux, and to the fact that the lines of force set up by the coils must either span an air-gap

1. Duncan. "Note on some experiments with Alternating Currents." TRANSACTIONS, vol. ix, p. 79.

many times larger than the clearance space, or else pass through the entire field circuit of the machine.

When in the 230° position and with a constant current of ten amperes flowing in the field circuit, and a constant current of 4.3 amperes flowing in coils 1 and 2, the ballistic galvanometer gave a deflection of 25 both at the "make" and at the "break" of the current. The current in the coils at this time was flowing in the same direction as that in which the alternating current is flowing when the coils are passing out from under the pole tips, and the armature is rotating in the normal counter-clock-wise

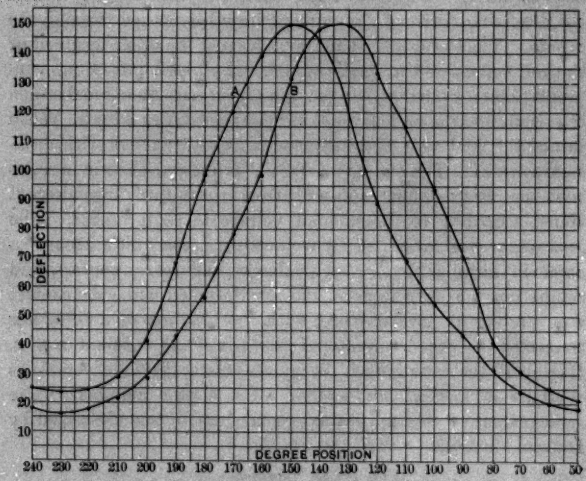


PLATE 1.

direction. From position 230° the coils were moved in a clock-wise direction, as viewed from the commutator end. This is opposite to the direction of rotation of the armature when running, but in the same direction as that in which the rotary contact brush was moved when the E. M. F. curves were taken. At the 220° position "make" and "break" readings both equal to 24 were obtained. At position 210° the readings gave 25 divisions again. At 200° they were all 30 divisions, and so on through one-half of a revolution of the armature. When plotted, these readings gave the curve A of Plate 1.

An inspection of this curve shows that it is distorted in the direction of the normal rotation of the armature. Thinking that its unsymmetrical form might not be entirely due to a magnetic reaction between the armature and fields, and that possibly it was caused, in part at least, by a variation in the width of the air-gap space, owing to the core of the armature not being quite true, the curve was continued through the complete revolution. The result of the test, however, gave another curve exactly like curve A. This indicated conclusively that lack of symmetry in the mechanical construcof the machine played no part in causing the distortion. The current in the coils 1 and 2 was then reversed in its direction while being kept at the same volume. The exploration resulted this time in giving the curve B, of Plate 1. As before, the "make" and "break" gave the same deflection for any given position, but the curve was found to be drawn over towards pole tips s′ and N, Fig. 2, instead of towards s and N′, as in the case of curve A.

The distortion of these curves, the ordinates of which are proportional to the inductance of the coils in various angular positions, is entirely due to the variation of the permeability of the iron composing the armature core and pole faces as the energized armature coils are moved through the half revolution. When curve A, Plate 1, was taken, the current passing through the coils tended to produce a magnetic field in opposition to that induced by the field circuit when the coils were in the 185° position, and one aiding the field flux when they were in the 95° position. In other words, poles were generated in the coils as indicated by the small N and s on coil 1 of Fig. 2. With the coils in the 95° position, when the circuit was made, a number of ampere turns were brought into action, which increased the induction in the surrounding masses of iron and at the same time decreased their permeability. With the coils in the 185° position, making the circuit through the armature, decreased the magnetic density in the surrounding iron and thereby increased its permeability. Breaking the armature circuit in either case brought the induction back to the same initial value, since the two positions assumed are symmetrically located relatively to the pole faces. The introduction of the same magnetizing force into the coils, however, does not cause the same variation in the induction threading the coils. Since the variation in the value of the permeability is in opposite directions in the two cases, the

variation in the flux in the 185° position is greater than that which occurs in the 95° position, and therefore the self-induction of the coils in the former is greater than in the latter, under the assumed conditions.

Magnetic hysteresis also plays a part in the variability of the armature inductance. As the armature revolves, the iron of the core passes through a complete hysteretic cycle once every revolution, and in making determinations of the armature inductance, account must be taken of the fact that the magnetization of the iron of the core follows the perimeter of the loop of hysteresis and not the "B and H curve," as the permeance of the core changes.

To determine the extent of the error introduced by neglecting to adhere to the true magnetic changes through which the iron passes, as is the case in the method so far described, a rather laborious process had to be resorted to of carrying the iron in the core completely through the hysteretic cycle before taking each reading. By this means, owing to the fact that when a coil is between the pole tips, the laminated core of the coil is highly saturated, it was possible to get a very fair estimate of the influence of hysteresis.

Suppose we take the hysteresis loop of Fig. 3 to represent the cycle through which the magnetization of the iron passes during a revolution of the armature. Let *a* represent the magnetic density in the core of coil 1 when it is in 230° position, and no current flowing in the coil. As the armature is revolved in a counter-clock-wise direction, the intensity of the magnetization in the core will decrease until at the 320° position it will have a value equal to *o*, *b*. At some point farther on, say at 330°, there will be a sufficient negative force to reduce the residual magnetism to zero, as at *c*, Fig. 3; and finally, when coil 1 reaches the 50° position, the magnetism will have been brought up to a negative maximum within the coil, as at *d*. If at this point the circuit is made through the armature coils, and a constant current sent through them in the direction which aids the field flux, the density in the core will be increased to a still higher value, and rise up to *e*. Suppose now that the armature is revolved still further round, for instance, to the 120° position. The flux penetrating the coil will diminish to *f*. If at this point the armature current is broken by the snap switch, a current impulse will pass to the galvanometer needle from the exploring coil, due to the

decrease in the induction threading the coil from f to g. If, without changing the position of the coil, the current is made again, the density will rise to h, but will not come up to the original value at f. In other words, any number of "makes" and "breaks" can be made after the first "break" with the same result, but the first "break" will give a larger reading than

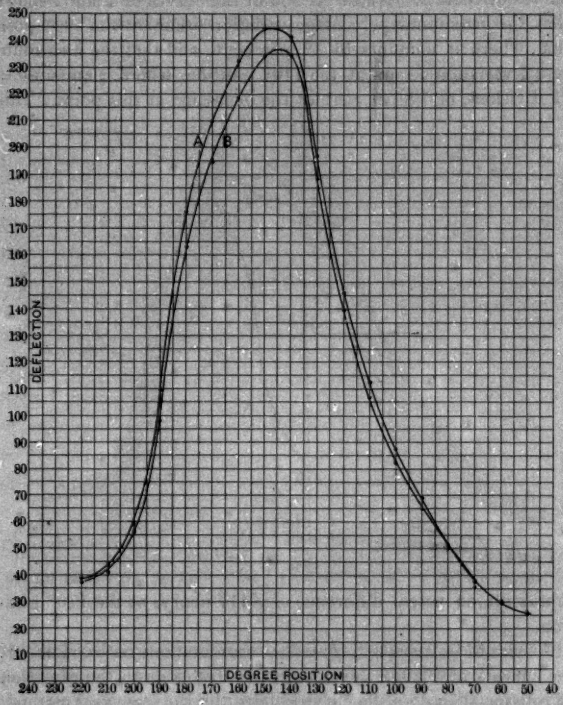


PLATE 2.

the others. The first "break" gives the most accurate result. By this method, however, coil 1 has to be brought back to the 230° position before taking each reading, then revolved counter-clock-wise to the 50° position, and, after the current is made, has finally to be moved to a position between s′ and s, to take the reading at the "break."

Following out this method for one set of readings, curve A, of Plate 2, was obtained. Curve B is a curve plotted from an average of the readings due to the second and third "breaks" and their corresponding "makes." It is identical with a curve taken by the method used in obtaining curves A and B, of Plate 1, but with the same armature current as that used in obtaining the curves of Plate 2. An inspection of the curves of Plate 2 shows that the maximum percentage variation occurs at the 190° position, where it amounts to 12 per cent., and that the maximum actual variation occurs at the 170° position, where it amounts to 15 divisions, or 7.8 per cent. of the deflection at this point. This

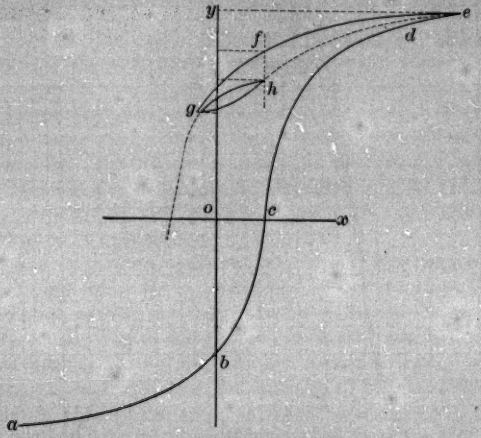


FIG. 3.

represents an actual difference of .0117 henrys at the 170° position.

As was to be expected, from the considerations outlined above, the curve A of Plate 2 shows a greater distortion in the direction of rotation than does the curve B, taken by the less exact method. It reaches a maximum later in the cycle, and although of uniformly greater amplitude than curve B, the differences are most marked in the last half of the cycle, counting time from right to left.

Curves A and B are, however, exactly similar in form and so nearly alike, that it was not deemed necessary to follow out the

more elaborate and exact method in succeeding determinations of the variable inductance, as the end in view was to determine the character of the changes occurring, rather than the absolute value of them.

Plate 3 exhibits a series of these inductance curves. They represent five explorations, made with direct currents of different intensities flowing through coils 1 and 2, while the field exciting current was maintained constant at 10 amperes, as usual. The

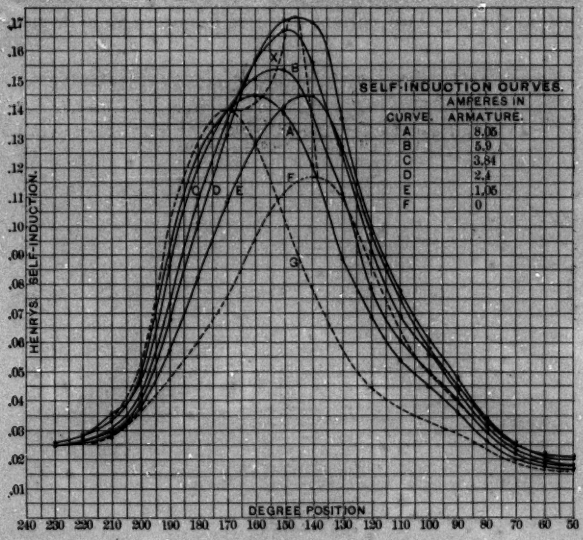


PLATE 3.

readings have been reduced to henrys; the calculation of the values being based upon the supposition that the inductance of the two coils at any point is proportional to the change in the number of lines of force existing in the coils at that point, divided by the current flowing in the coils and producing the change. The plotted values, therefore, represent the inductances of the two coils in series, proper allowance having been made for the fact that the exploring coil was only wound about one of them.

The curves of Plates 4 and 5 have been derived from those of

Plate 3. They show the relation between the direct currents flowing in the coils and the inductance of the coils, and are useful when it is desired to determine the curve of instantaneous inductance that corresponds to a given alternating current wave.

The curves of Plates 3, 4 and 5 bring to light some very interesting facts. They show that the maximum coefficient of self-induction occurs when the coils are in the 145° position and the current flowing in them has a value of 2.5 amperes; under these conditions their inductance is over .172 henrys. They indicate that as the armature current is varied from zero up to its max-

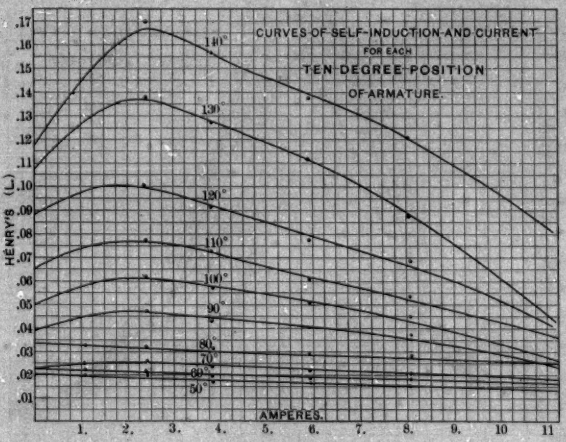


PLATE 4.

imum safe value, the inductance of the coils undergoes very marked and relatively rapid changes. The dotted curve F has been plotted from the ordinates of the curves on Plates 4 and 5 that correspond to the zero value of current. It represents the initial inductance cycle, and is the basic curve to either side of which the inductance curves for the various currents fluctuate. Curve F is practically symmetrical relatively to the pole faces. Its crest occurs as the coils pass the centre of the pole faces, and it slopes equally on either side. The line X, drawn from its crest through the crests of the other curves, indicates the successive positions and values assumed by the maximum inductance cor-

responding to different constant currents, as the volume of these currents is increased from zero. The maximum current carrying capacity of the armature is 15 amperes, but the inductance is changed from its maximum initial value of .117 henrys to its maximum possible value of .172 henrys when the armature current reaches 2.5 amperes. Any further increase in the current causes the amplitnde of the inductance wave to diminish, and at 8 amperes it is only 85 per cent. of what it is at 2.5 amperes.

Besides varying in amplitude, the inductance waves undergo a lateral shifting in the direction of the rotation of the armature.

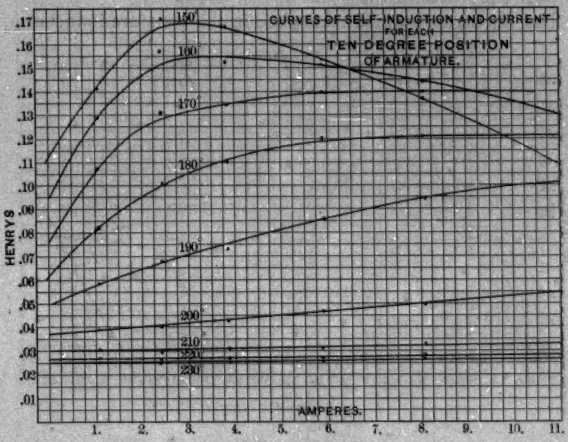


PLATE 5.

The dotted curve c has been taken from Plates 4 and 5, and represents the inductance curve corresponding to 11 amperes. An inspection of Plate 5 shows that this curve practically marks the limit of the variability of the inductance. For a further increase in the current, the 170° curve of Plate 5, tends to remain horizontal, and the 180° curve exhibits no disposition to rise appreciably beyond the 11-ampere point, there will therefore be practically no further shifting of the crest, or change in the amplitude of the induction curve.

To better appreciate the extent of the distortion that occurs, it is well to note that at the 170° position there is a difference of

about .065 of a henry between curves A and F of Plate 3, showing that the inductance of the coils at this point has double the value at full load that it has at no load. This fact is brought out strongly in Fig. 4, which shows the differences between the ordinates of curves D, F and G. In this figure, the amounts by which the ordinates of curves D and G of Plate 3 differ from those of curve F have been plotted as ordinates relatively to curve F reduced to a horizontal base line.

It is also interesting to note that between no load and full load, the crest of the induction curve moves through an angle of 30°, or over one-fourth of the width of the pole faces.

The fluctuations which take place in the armature inductance,

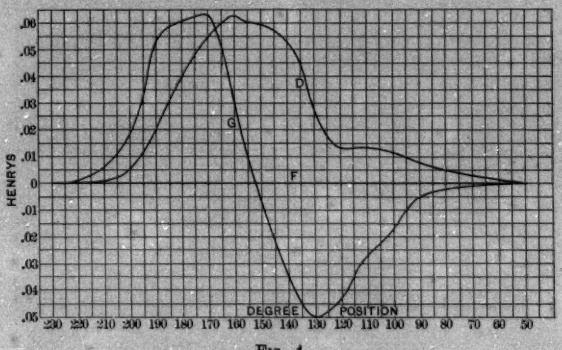


FIG. 4.

are due to the changes occurring in the reluctance of the path traversed by the flux induced by the armature current. The action of the armature current is to intensify the induction in the armature core between the 60° and 130° positions of coil 1. The initial induction in the core was over 24,000 gausses when the coils were between the pole tips. The armature current acting with the field excitation maintained this saturation during the first part of the revolution and prevented any great variation in the induction in the first quadrant. But during the second and fourth quarters of each revolution, when the coils were between the 170° and the 200° positions, the armature current was reacting against the field excitation, and thereby, by diminishing the flux density, was increasing the permeance of the iron and

the inductance of the coils for these positions. The magnetizing power of the coils is considerable, as with 8 amperes flowing through them, they set up an induction of 18,000 gausses in the core when in the 160° position.

The great amplitude of the induction wave for 2.4 amperes in the coils is in the same way due to the fact that the permeance of the path is least when the magnetizing force is that due to

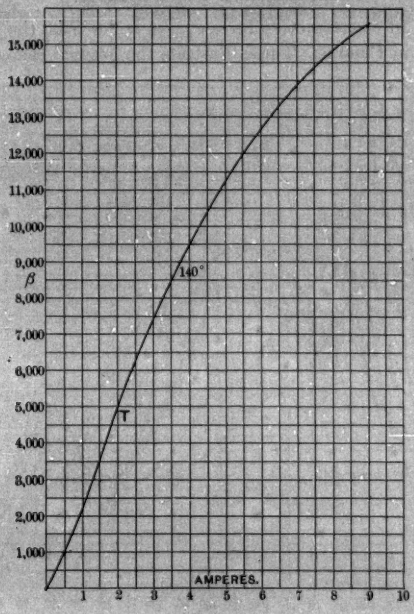


FIG. 5.

this current. If we plot the values of the 140° curve of Plate 4 in terms of the armature current and the induction set up in the core by the current, we obtain the curve shown in Fig. 5. This is "B and H" curve for the magnetic circuit through the armature core in this position, and the point T which corresponds to the maximum ordinate of the 140° curve, is the point where a tangent to the curve makes the greatest angle with the base line.

The large teeth of the armature core do not seem to have the

effect of causing any marked irregularities in the inductance curves. It is noticeable, however, that there is a slight hump in all of them at the 90° position. This is caused when the teeth immediately behind the coils pass the pole tips. The same effect is produced by the other teeth, but it is too slight to appreciably affect the readings.

Electromotive Force Curves.

A series of electromotive force curves taken from the machine are shown in Plate 6. These illustrate the gradual change in the

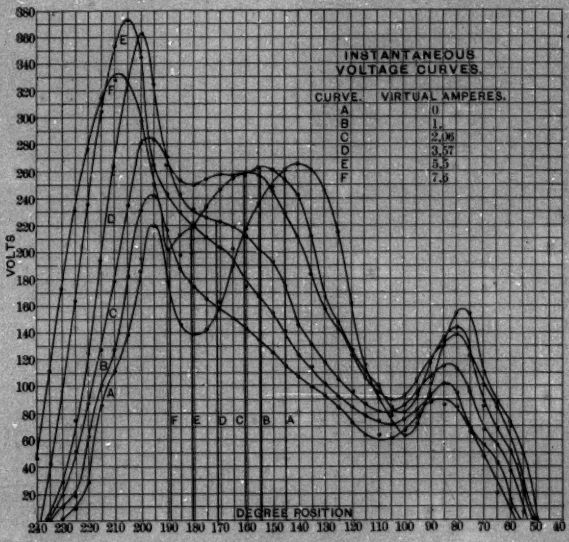


Plate 6.

wave form of the effective electromotive force as the load increases. By the effective electromotive force is meant the electromotive force that is in phase with the current and overcomes the ohmic resistance.

There is quite an appreciable lag in the effective electromotive force for the higher loads, owing to the armature inductance. This can hardly be regarded in the light of a simple phase displacement, as the lag partakes largely of the nature of a trans-

formation of the fundamental wave A, that is due to the phase positions of the higher harmonics being shifted relatively to the fundamental harmonic, and not to any material change in the phase position of the fundamental harmonic itself. The extent of the shifting is best appreciated by noting the positions of the ordinates A, B, C, D, E and F. These lines bisect the areas of the electromotive force curves designated by corresponding letters, and indicate the points at which the induction threading the coils passes through zero and changes sign.

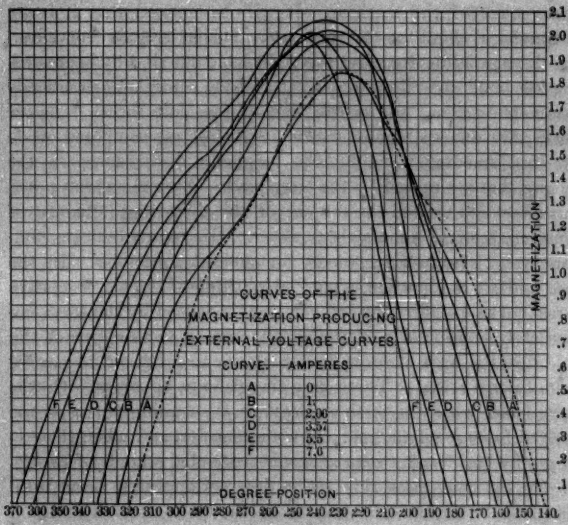


PLATE 7.

The curves of Plate 7 have been determined from those of Plate 6 by integrating the areas of the latter. They illustrate the waves of magnetism producing the effective electromotive force curves, and give a better idea of the extent of the lag that takes place. The scale of ordinates of Plate 7 expresses the value of the integral,

$$\int e\, dt = -N, \qquad (1)$$

as determined from the curves of Plate 6, and must be multiplied by the constant 12206 to express the value of the induction per sq. cm. in the iron of the armature core. The maximum induction occurring in the core is therefore a little over 25,000 gausses.[1] In determining the value of the constant, an allowance of 20 per cent. was made for the lamination of the iron, 80 per cent. of the gross area of the core being used as the equivalent of the iron.

Curve A of Plate 6 was obtained with zero current in the armature. This is the "fundamental" or internal electromotive force wave of the machine. It will be noticed that it is not symmetrical about the 140° ordinate. It is an irregular curve having three prominent peaks; the right hand one slightly depressed, the left hand one raised somewhat, and the central one practically symmetrical about the centre line of the pole faces. The ear peaks are due to higher harmonics being superimposed upon the fundamental wave by the magnetic disturbances in the air-gap that are caused by the large teeth. Steinmetz[2] has noted this effect and treated the subject of the distorting influence of armature teeth in a masterly manner. His results indicate comparatively symmetrical waves for no-load conditions. In the case under consideration, a marked shifting of the electromotive force curve in direction of rotation is caused by the teeth immediately on each side of the coils. As the teeth approach the pole tips, the lines of force do not appear to reach out to receive them to any extent. There is a sluggishness apparent. On the other hand, when the teeth are leaving the trailing pole tips, the lines of force seem to hold on with tenacity, and when they do let go, fly back with a snap as would extended strands of elastic. In the extreme cases, this action does not appear to occur until the tooth is over an inch away from the pole tips. The rapid cutting of the lines necessarily augments the potential at this point.

This explanation has its bearing upon the case, but the distortion is perhaps better explained by looking at it in the light of the part played by hysteresis and eddy currents. The eddy currents induced in the pole tips tend to oppose any change that

1. Some elaborate tests were made on Brush dynamos in 1889, by Mr. Murry. The values of B attained were about 4,800 gausses in the field, and 27,000 in the armature cores. See S. P. Thompson's "Dynamo Electric Machinery," p. 464, 1892 edition.

2. C. P. Steinmetz, TRANSACTIONS, vol. xii., p. 470.

takes place in the field distribution of the induction. They help to maintain a high induction in the trailing pole tips, and keepdown the induction in the leading pole tips. The iron in the core of the armature is being carried through a complete hysteretic cycle at each revolution. The iron in the pole tips is carried through an hysteretic loop with the passage of each tooth across the pole face. At the leading pole tips the magnetism in the core iron is always working on the descending portion of the curve of hysteresis, and the reluctance of the magnetic circuit by the leading pole tips is increased accordingly. At the trailing pole tips the iron is worked on the ascending side of the hysteretic curve, and the reluctance of the path by the trailing pole tips is thereby reduced. The same magnetizing force, therefore, acting upon the two paths, induces a distorted field when the armature is running, and a symmetrical field when the armature is at rest, as shown by curve A and the dotted curve of Plate 7. The latter curve was obtained by exploring the air-gap distribution of the flux by the ballistic method, using the exploring coil wound over coil 1, and breaking the field circuit.

The activity displayed by the eddy currents in heating up the pole tips is quite remarkable. The curves B and A of Plate 8 indicate the rise in temperature of the leading and trailing tips, respectively, throughout a two hour's run. The readings were taken from thermometers fastened directly to the pole pieces. The curve C is a curve of differences derived from curves A and B, and it indicates how very much more rapidly than the temperature of the leading pole tips the temperature of the trailing pole tips rises during the first twenty minutes of the run. Their differences in temperature after that time is practically constant. The curves plainly indicate that much greater magnetic disturbances occur in the leading pole tips than at other points in the pole faces. The thermometers had to be fastened to the back of the pole tips during the test, had it been possible to place them in contact with the air-gap face, more rapid changes would doubtless have been recorded. During the test the field coils were excited with a current of 10 amperes, and the armature was loaded to about 5 amperes. At the end of the run, the temperature of the armature was 42° C.

As the armature core has sixteen teeth, or four per pole face, we may expect harmonics as high as the ninth to play a prominent part in the wave structure.[1] The general form of the internal

1. C. P. Steinmetz, TRANSACTIONS, Vol. xii, p. 475.

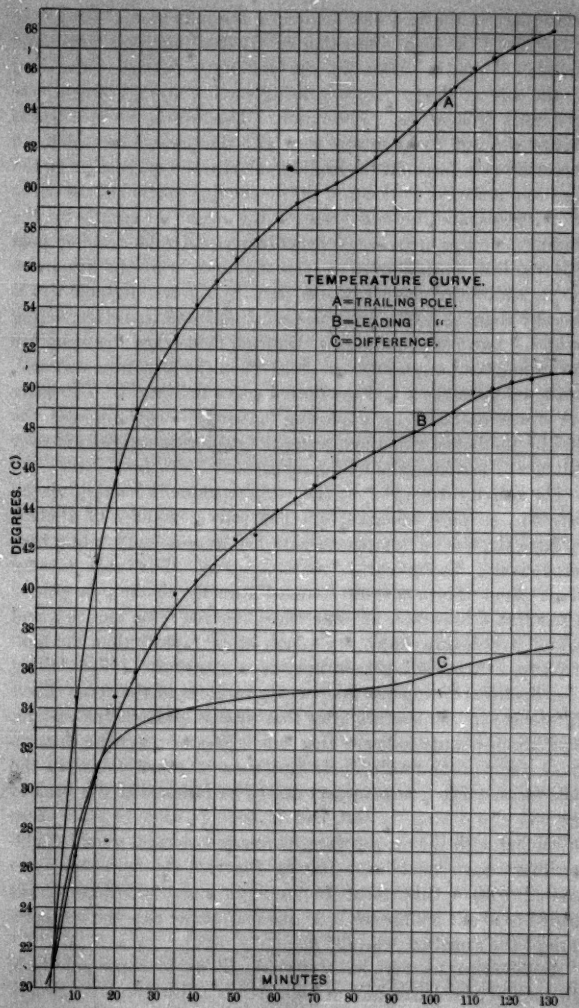

TEMPERATURE CURVE.
A=TRAILING POLE.
B=LEADING "
C=DIFFERENCE.
A
B
C
DEGREES. (C)
MINUTES
10 20 30 40 50 60 70 80 90 100 110 120 130

PLATE 8.

electromotive force curve A is indicative of the fifth harmonic; the side peaks have been sharpened, however, by the upper harmonics, and the central one somewhat broadened by the third.

The wave form of the electromotive force induced in the armature when the machine is loaded depends upon the character of the inductance curve of the armature coils. As already explained the effect of the teeth upon the inductance curves is to introduce harmonics and cause irregularities in their contours. Practically the same number of harmonics are prominent in all the electromotive force curves, although the armature inductance has the effect of smoothing out the irregularities by giving the third harmonic greater prominence, and diminishing the effect of the higher harmonics. As the current rises and the magnetizing power of the armature becomes apparent, the harmonics introduced into the circuit by the variable inductance grow in amplitude. They combine with the harmonics of like order of the fundamental wave, and an electromotive force curve results that is compounded of a series of harmonic that depend upon the value of the armature current for their amplitude and phase positions.

A very small amount if any of the change in the form of the effective electromotive force waves is due to any departure of the original no-load wave of field flux from its initial wave form. In fact, to all practical intents and purposes the pulsations that occur in the magnetic reluctance of the field circuit are sensibly of the same intensity at full load as they are at no load. In other words the changes that occur in the permeance of the core of the armature as the load varies do not appreciably alter the permeance of the field circuit. The fundamental wave of magnetism and of electromotive force may therefore be regarded as always being present, if not always tangible.

Where alternating current generators are operated on circuits having a constant resistance for constant conditions of load, the disturbances that modify the form of the electromotive force and current waves can be attributed to the cyclic variations in the inductance of the system, and when these are known within a fair degree of approximation the character of the wave modifications that will result can be determined.

In the development of the experimental results contained in this paper the dynamo was loaded by inserting sets of incandescent lamps in the external circuit. A special point was made of keeping the external circuit entirely free of any inductance. The

current curves are therefore necessarily proportional to the electromotive force curves. However, to make their relative value and form more easy of appreciation, they have been plotted and

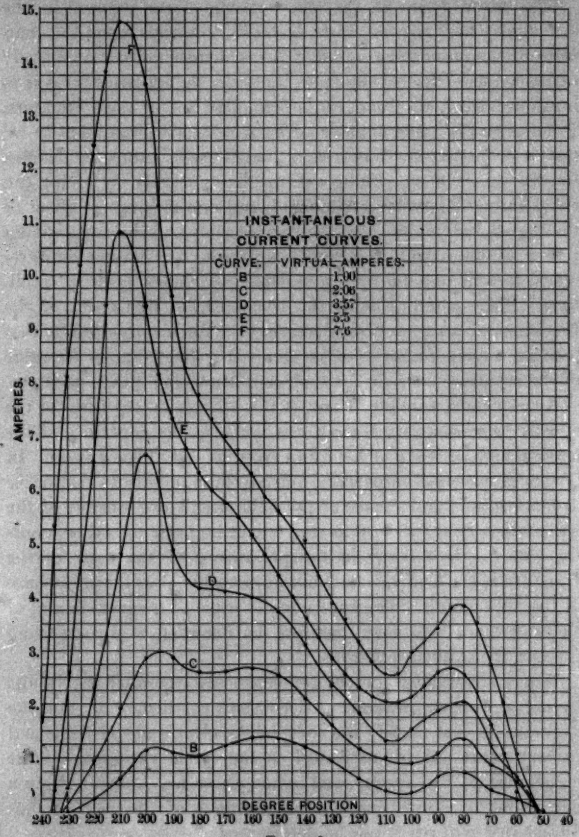


PLATE 9.

are shown in Plate 9. The inductance curves of the coils that correspond to the alternating current curves are given in Plate 10. These curves were determined by selecting from the curves of

Plates 4 and 5, inductance values corresponding to the instantaneous values of the current curves and plotting them to the same degree positions.

It is noticeable, owing to the different scales used in plotting the curves, that the current curves seem more even and smoother than the electromotive force curves. The inductance curves also are more nearly alike, both in phase and in amplitude than the curves of Plate 3. This is owing to the fact that the alternating currents all start from, and end at zero values when the coils are in positions of slight inductance, while they attain their maximum values at points of large inductance. For this reason the average inductance per cycle of the coils is greater with an alternating current flowing in them than with a direct current of the same effective value. The alternating currents, for analogous reasons, force the induction curves up to the saturation limit marked by curve G of Plate 3, more rapidly than do the direct currents, and therefore for the same variation in effective current strength a less marked variation is caused in the inductance curves with these currents. The curves of Plate 3 certainly lead us to expect a greater variation, relatively to current intensity, in the armature inductance when the armature is in actual operation than that which is depicted in Plate 10.

It is a curious coincidence that the alternating current inductance curves all cross at a common point: namely, at the 164° position.

Counter Electromotive Force[1] Curves.

Having the instantaneous current and inductance curves corresponding to a series of loads on the machine, it was a comparatively easy matter to determine the curves of the counter electromotive forces developed in the armature. To obtain a curve showing the cyclic variation of the induction set up in the coils by the armature current it is only necessary to plot the products of the ordinates of corresponding points on corresponding current and inductance curves. Such a set of curves obtained from a combination of the curves of Plates 9 and 10 are given in Plate 11.

If N represents the total flux that is induced in both coils by the armature current, divided by 10^8; L represents the inductance

1. In this paper the term "counter E. M. F." is used to indicate the E. M. F. which added to the effective E. M. F. will equal the fundamental E. M. F. The counter E. M. F. is therefore equal and opposite to the inductance E. M. F., or the E M F. of self-induction.

of the coils connected in series in henrys; s represents the total number of turns (572) of wire in both armature coils; and A represents 80 per cent. of the gross area of the armature core inside the coils, or 11 sq. cms.

Then the induction per sq. cm. in the coils due to the armature current will equal,

$$B = \frac{N \times 10^8}{S\,A} = 15892 \times N. \qquad (2)$$

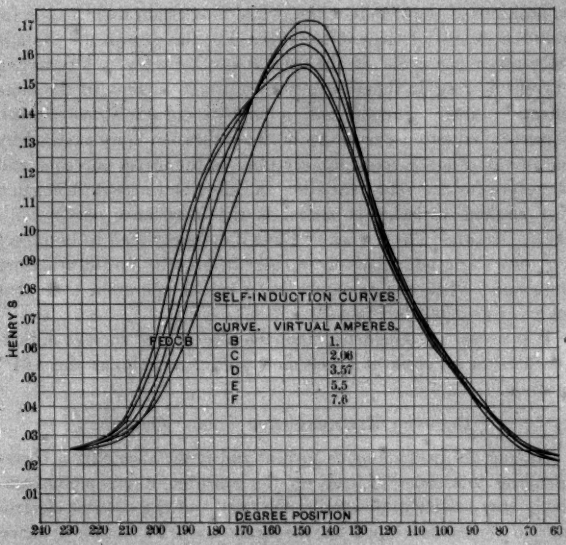


PLATE 10.

This equation gives the constant (15892) that must be applied to the scale of ordinates in Plates 11, 12 and 13 to determine the actual core densities induced by the armature currents.

Again, if i represents the instantaneous value of the armature current,

$$N = L\,i. \qquad (3)$$

and

$$d\,N = L \times d\,i + i \times d\,L, \qquad (4)$$

since L is a variable. Therefore, the counter electromotive force developed in the coils equals

$$e = -\left(-\frac{dN}{dt}\right) = \subset\left(L\frac{di}{dt} + i\frac{dL}{dt}\right). \qquad (5)$$

In Plates 9, 10 and 11, we have the necessary curves for de-

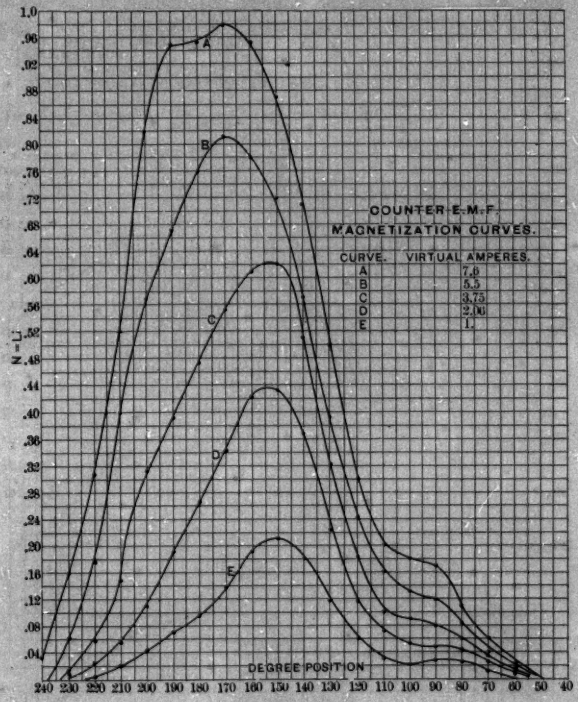


PLATE 11.

termining the instantaneous values of the counter electromotive force corresponding to any degree position by applying the principles underlying either of the above expressions. Both methods were used and were found to check within narrow limits. In Plates 12 and 13, the curves marked A have been taken from Plate 11. The ordinates of the curves marked B are equal to the

tangents of the angles made with the horizontal axis by lines drawn tangent to the A curves at the extremities of corresponding ordinates. The B curves are the calculated curves of counter electromotive force developed in the armature. The dotted curves were obtained by subtracting curves D and E of Plate 6

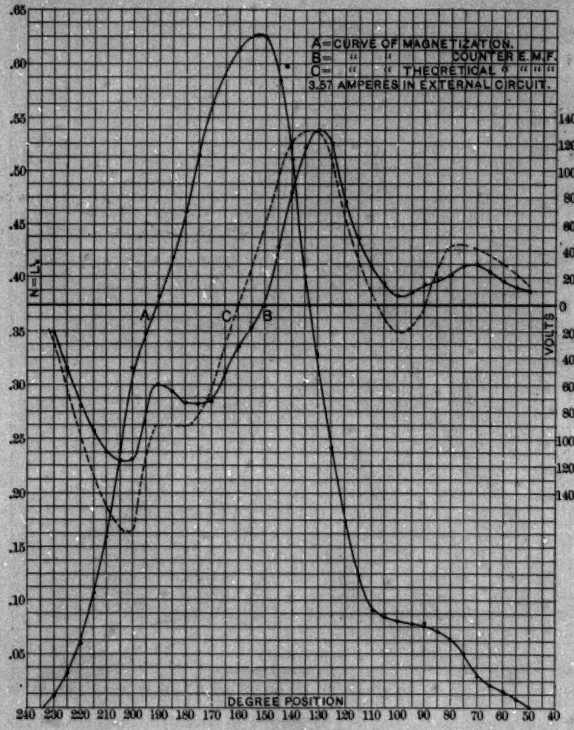


PLATE 12.

from curve A of Plate 6. On the assumption that the fundamental electromotive force wave of the machine does not change with the load, the dotted curve should also represent the counter electromotive force curve of the armature, and, in fact, the two curves should coincide. Plate 12 represents the poorest, and

Plate 13 one of the best results obtained from the application of this construction to each of the five sets of curves taken from the dynamo. When the fact is taken into account that the inductance of the coils was determined when the armature was at rest, the likeness between the dotted and the full curves is quite remarkable, and apparently justifies the assumptions that have been made. The counter electromotive force curves are highly

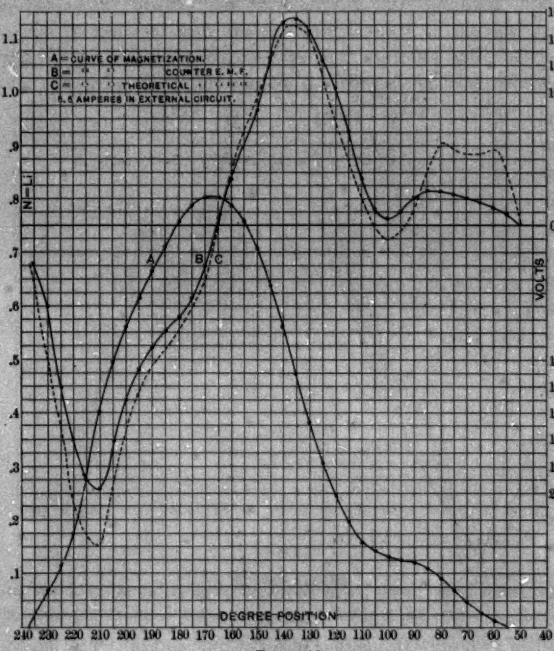


PLATE 13.

irregular in form. They oscillate from the positive to the negative value twice in a period instead of once, and are generally useful in filling up gaps. As shown, the curves represent the halves of one of the positive and of one of the negative loops; in other words, the half period of the curves lies between the 350° and 170° positions, and not between the 50° and 230° posi-

tions. This will be made more evident by a reference to curve c of Plate 18.

The whole series of inductance curves, as obtained by the subtraction method, are plotted in Plate 14. This assemblage shows that the curves follow one another in regular order in spite of their *lack of symmetry*, and it is interesting to note the receding of one and the building up of another "hump" in these curves, as illustrated at the lower left hand edge of the sheet.

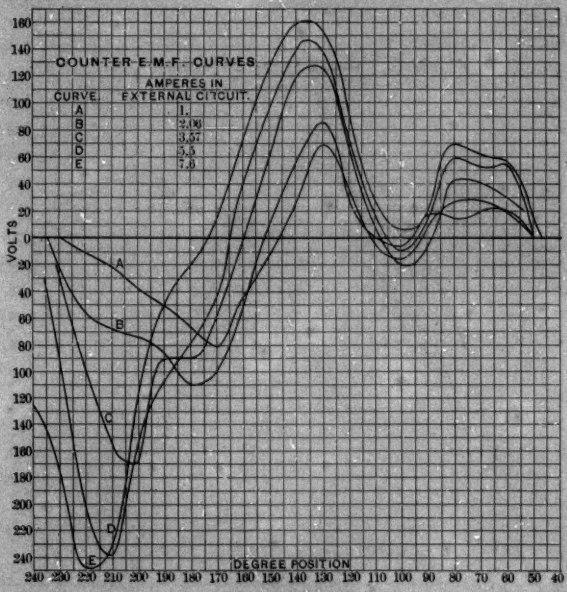


PLATE 14.

Plate 15 represents another phase of the subject. The curves traced in the fine black lines are the results of adding the calculated electromotive force curves determined by the means illustrated in Plates 12 and 13, to the corresponding effective or external electromotive force curves of Plate 6. They show the result of an attempt to work back from the effective electromotive force curves, or from the wave form of electromotive force appearing at the collector rings when the machine is loaded, to

the fundamental electromotive force wave or the electromotive force wave appearing at the collector rings when the machine is running on open circuit.

The curve A, reproduced on this plate for comparison with the curves just mentioned, is the same as curve A of Plate 6. The agreement between the curves is marked. The derived curves show the greatest departure from the fundamental curve early in the cycle, between the 70° and the 110° positions. This is due to the fact that the initial "hump" at the 90° position of the induction curves was not developed with sufficient care. A very slight change in the contour of the induction

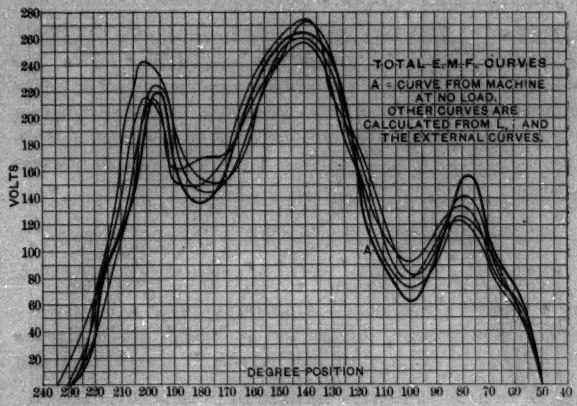

TOTAL E.M.F. CURVES
A = CURVE FROM MACHINE AT NO LOAD.
OTHER CURVES ARE CALCULATED FROM L, I AND THE EXTERNAL CURVES.
VOLTS
DEGREE POSITION
A

PLATE 15.

curves at this point makes a great difference in the form of the counter electromotive force curves, owing to its effect in altering the direction of the tangents drawn to the magnetization curves of Plate 11. On the whole the likeness between the curves is well within the limits of the errors of observation.

DERIVATION OF CURRENT CURVES.

Another interesting set of curves is shown in Plate 16. The success attained in working out the counter electromotive force curves led to a series of calculations to determine to what extent the form of the current curves was influenced by the shifting of

the phase of the inductance curves with the load. To this end an average of the inductance waves A, B, C, D and E of Plate 3 was taken to represent the average inductance wave of the armature for all loads. This curve is shown as curve B of plate 16. With this curve and the fundamental electromotive force wave A, forming a basis for calculation, the current that will flow with any given resistance in the circuit can be readily determined, provided that the curve B is taken to represent all of the variations that occur in the armature inductance.[1] The relation existing be-

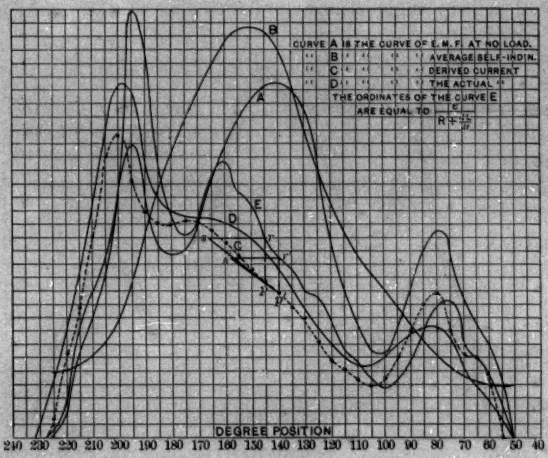

CURVE A IS THE CURVE OF E. M. F. AT NO LOAD.
" B " " " " AVERAGE SELF-INDN.
" C " " " " DERIVED CURRENT
" D " " " " THE ACTUAL "
THE ORDINATES OF THE CURVE E
ARE EQUAL TO
DEGREE POSITION
240 230 220 210 200 190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40

PLATE 16.

tween the impressed electromotive force, the current and inductance in any alternating current circuit similar to the one under discussion is expressed by the equation

$$e = Ri + \frac{dN}{dt}, \qquad (6)$$

There e, i and $\left(\frac{2N \times 10^8}{S}\right)$ are, respectively, the instantaneous

1. Steinmetz, "On the Law of Hysteresis." TRANSACTIONS, vol. xi., p 574. In this article the author calls attention to the solution of a problem that is analogous to this one, differing from it only to the extent that he works from an assumed sinusoidal inductance-electromotive force and a circuit of negligible resistance.

values of the impressed potential, current, and the magnetic flux induced by the current, and R is the resistance of the circuit.

Since $N = L\,i$, as above, (see equation 1), in the present case we have:

$$e = R\,i + L\frac{d\,i}{d\,t} + i\frac{d\,L}{d\,t}. \tag{7}$$

Then,

$$i\left(R + \frac{d\,L}{d\,t}\right) = e - L\frac{d\,i}{d\,t}, \tag{8}$$

and

$$i = \frac{e}{\left(R + \frac{d\,L}{d\,t}\right)} - \frac{L}{\left(R + \frac{d\,L}{d\,t}\right)} \times \frac{d\,i}{d\,t}. \tag{9}$$

By applying this formula to the curves of Plate 16, and following out a graphical construction, the successive instantaneous values of the current were finally determined, although in accomplishing this result the current curve E, which was the outcome of the process, had to be carried through successive cycles until it repeated itself.

The values of $\left(\frac{d\,L}{d\,t}\right)$ were taken from curve B. The ordinates of the curve A were then divided by the corresponding values of $R + \frac{d\,L}{d\,t}$, and these quotients, when plotted, gave the curve E.

Next, referring still to Plate 16, a point, as for instance p, was taken, that was thought to lie near the current curve, and the line $(p'\ r')$ drawn. From (r') the line

$$(r'\ s') = \frac{L}{R + \frac{d\,L}{d\,t}} \tag{10}$$

was laid off and $(s'\ p')$ drawn. Now from the assumed position of p',

$$\frac{p'\ r'}{r'\ s'} + \frac{p'\ r'}{\left(\frac{L}{R + \frac{d\,L}{d\,t}}\right)} = \frac{d\,i}{d\,t}, \tag{11}$$

and $(p'\ s')$ established the direction of the current curve, since from equation (9),

$$\left(\frac{L}{R + \frac{d\,L}{d\,t}}\right)\frac{d\,i}{d\,t} = \frac{e}{R + \frac{d\,L}{d\,t}} - i, \tag{12}$$

and

$$\frac{di}{dt} = \frac{\dfrac{e}{R+\dfrac{dL}{dt}} - i}{\left[\dfrac{L}{R+\dfrac{dL}{dt}}\right]} \tag{13}$$

and therefore,

$$(p'\,r') \text{ approximated the value of } \frac{e}{R+\dfrac{dL}{dt}} - i. \tag{14}$$

By taking another point p on p' s', and continuing the construction, a chain made up of short lengths $p'\,p$ was obtained which ultimately developed into the periodic wave C, for which the values of

$$p'\,r' = \frac{e}{R+\dfrac{dL}{dt}} - i. \tag{15}$$

The graphical construction used is not new. It is an adaptation of one of Dr. Sumpner's[1] unique methods of treating alternating current problems, and I have developed it here simply as a matter of interest in connection with the discussion.

Returning to the curves, it is noticeable that the dotted curve C resembles the current curves of Plate 9 very closely. Comparing it with curve D, which is a current curve taken from the machine, with 55 ohms resistance in the complete circuit, the chief difference noticed is that the right hand peak of the dotted curve is a little high, and the left hand peak a little low, and that the curve as a whole is somewhat depressed below the curve D. The differences between the curves are, however, not very marked. They result largely from the curve B having a less amplitude and smaller slope than the alternating current inductance curves of Plate 8, since it is derived from the direct current inductance curves of Plate 3.

The construction indicates a method that can be employed with success in determining before the machines are built, the wave forms that will be developed by alternators. It is possible to predetermine the fundamental electromotive force and inductance waves of an alternator, by the application of modern

1. Dr. W. E. Sumpner, *Philosophical Magazine*, June, 1887, p. 470.

methods of design, and from these the load curves and armature reactions can be ascertained by processes analogous to those shown here.

If in the present case it had been desired to calculate the actual current curve with great exactness, an extension of the method used could have been employed. This elaboration necessitates taking the inductance values from Plates 4 and 5, as each point on the current curve is fixed. The process represents a refinement, however, that is hardly warranted in view of the good approximations resulting from the use of the less tedious plan.

Over-Compounding.

It was noticed during the test that the armature reaction caused an increase in the total effective potential for certain ranges of load.

This phenomenon has been noted by other writers, and in his paper before the Institute, already referred to, Steinmetz has pointed out an explanation for it. Curve A of Plate 17 is the external characteristic of the dynamo, with constant field excitation, and coils 1 and 2 alone in action. The curve was plotted from the readings of a Weston voltmeter and a Siemens dynamometer connected in the external circuit. The load was a non-inductive one, and the speed of the dynamo averaged 1,450 r. p. m., which is equivalent to a frequency of a little over 24 periods per second.

The line R represents by its slope the resistance of the two coils, and curve B, which was obtained from the sum of the ordinates of the curves A and R, is the total effective E. M. F. characteristic of the coil. It will be noticed that the curve B shows an over-compounding effect up to a load of 7 amperes, and that the total effective E. M. F. was a maximum for a current of 4 amperes in the coils.

The term "armature reaction," as used above, is not intended to convey the idea that the current in the coils has any effect in varying or modifying the intensity of the flux passing through the field spools. The influence of the M. M. F. of the coils is purely a local one, and the paths traversed by the flux which it induces are confined to the air-gaps, poles and armature core. The influence of the armature inductance upon the flux density in the cores of the field spools is negligible, as a careful exploration established the fact that the field current was perfectly constant.

The compounding action of the armature currents in augmenting the effective voltage is a matter with which you are doubtless familiar. As a matter of interest, however, and in order to present a better picture of the wave forms involved, a series of curves has been plotted, that includes the power curves, and enables us to

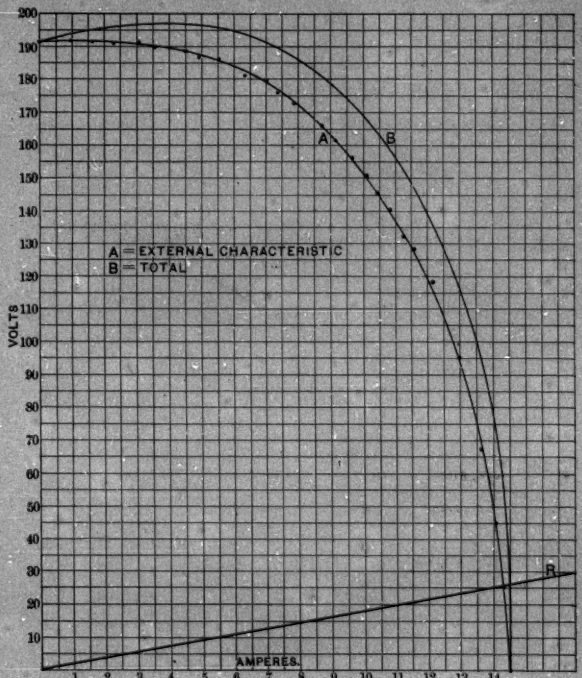


PLATE 17.

more readily appreciate the cycle of events that combine to produce this result. In Plate 18, curve A is the fundamental E. M. F. wave; curve B is the total effective E. M. F. wave and also represents the instantaneous values of the current; and curve C is the counter E. M. F. wave. Curve D is the power curve of the machine determined by taking the product of the corresponding in-

stantaneous values of the current and the fundamental E. M. F. curve. Curve E is a power curve obtained by taking the product of the corresponding values of the current and the counter E. M. F. The power curve of the total power developed by the machine, and which is proportional to the product of the corresponding values of the current and effective E. M. F. curves, is not plotted, as its ordinates are proportional to the square of those of curve B, and equal to the vertical distances intercepted between the power curves D and E.

It will be noticed that the power area inclosed between the curve E and the base line changes sign four times in a complete period, owing to the irregular form of the curve C, and that the sum of its positive and negative areas is not zero, but equal to a negative quantity.

Positive work done by the counter E. M. F. indicates power absorbed from the circuit. The energy consumed in overcoming the hysteresis and eddy current losses in transformer cores is a familiar example of this fact. Negative work performed by the counter E. M. F. in the same way represents power given to the circuit. In the present instance the negative area is due to a peculiar combination of irregular wave forms, involving the inductance curve, the current curve, the curve of the magnetism inducing the counter E. M. F., and the curve of counter E. M. F. The peaks of all the curves are shifted more and more in the direction of rotation as the load comes on, but some are given a greater displacement than others. The peak of the current curve, for instance, lags behind the peak of the inductance curve. In other words, the current is a maximum when the inductance is least. This results in the production of a wave of M. M. F. of self-induction that is in advance of the current, and that produces a wave of magnetism in the coils which reaches a maximum midway between the peaks of the inductance and current curves. These phase relationships can be followed out by comparing Plates 10, 9 and 11. The wave of inductance magnetism (curve A, Plate 11) induces a curve of inductance E. M. F. that has an effective phase displacement behind the current wave of less than 90°. This makes the effective phase displacement of the counter E. M. F. curve (curve C, Plate 12, and curve C, Plate 18) more than 90° in advance of the current curve, and therefore the product of the instantaneous values of the counter E. M. F. and current curves gives a power curve having an excess negative area. It is rather

difficult to estimate the phase position of a wave that has an outline as irregular as that of the curve C of Plate 18, but it is best approximated by noting the location of its greatest positive area, and this, in the case in hand, is early in each half period.

Conclusions.

An inspection of curves B and D of Plate 18 shows that any decrease in the maximum slant of the curves of Plate 11 will decrease the amplitude of the 200° peaks of the counter E. M. F. curves, and thereby decrease their form factors, and at the same time decrease the form factors of the effective E. M. F. curves. This is what occurs in the case of curve D of Plate 11, owing to the great amplitude of the inductance loop for a value of the current of two amperes, which also accounts for the drop in the "form factor curve" of Fig. 6. This curve represents the form

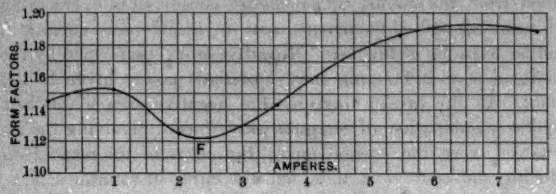


Fig. 6.

factors of the E. M. F. curves of Plate 6, and of the current curves of Plate 9, plotted relatively to the virtual value of the current flowing in the coils at the time the curves were taken. The form factors have been calculated according to Fleming's[1] definition, which is that the form factor equals the ratio of the square root of the mean square of the ordinates of the wave to the true mean ordinate of the wave.

The influence of the inductance of the coils upon the form factor can best be appreciated by looking at the curves of Plate 10. They all have the same width of base, but vary in amplitude, and necessarily other things being equal, produce counter E. M. F. curves having the smallest form factors when currents which are favorable to a large armature inductance are flowing in the coils.

1. J. A. Fleming, "The Form Factor of Alternate Current Curves." London *Electrician*, vol. xxxvi., p. 388.

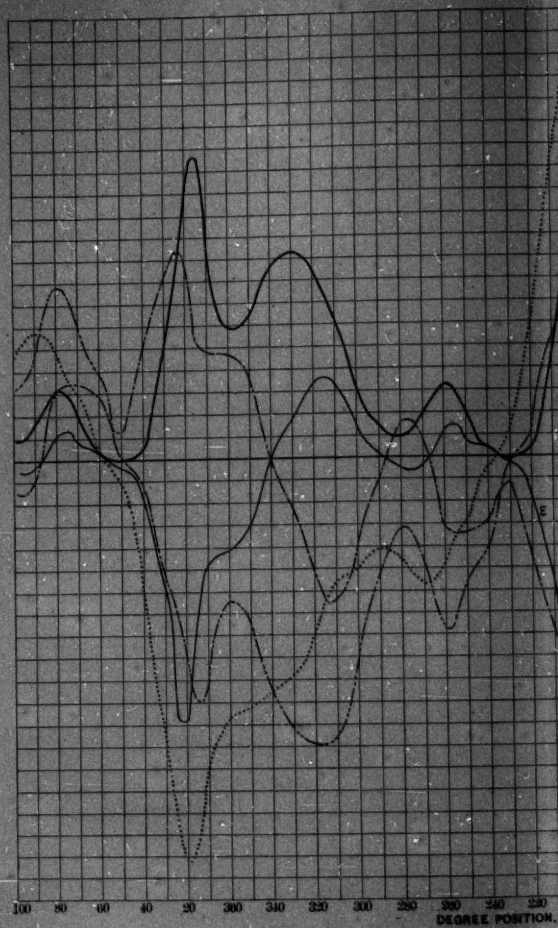
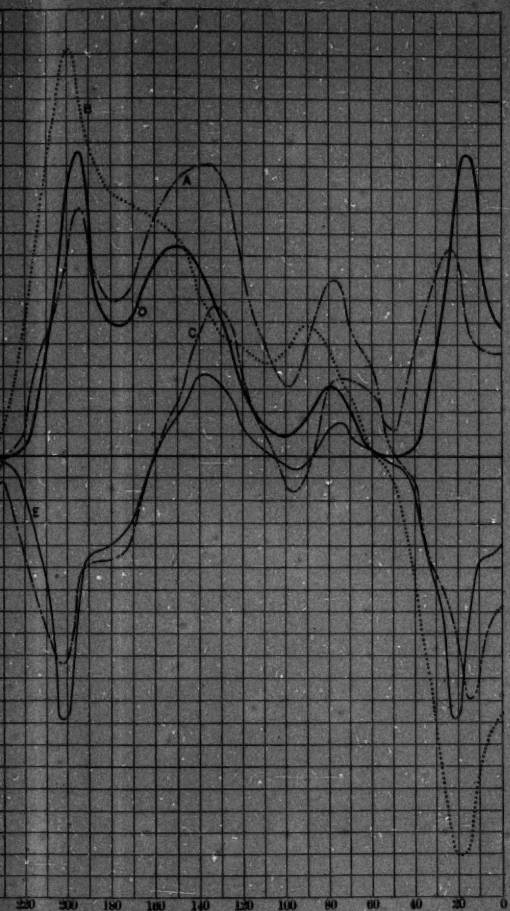


PLATE 18.

A = Fundamental E. M. F. wave.
B = Total effective E. M. F. curve and c
C = Counter E. M. F. curve.
D = Fundamental E. M. F. power curve.
E = Counter E. M. F. power curve.
The total power developed is represente
the curves D and E.



SITION.

= 18.

and current curve.

curve.

).

resented by vertical distances between

It is noticeable that the right sides of the curves of Plate 10 all have the same slant. They therefore produce counter E. M. F. loops, having similar shapes (see Plate 14). On the other hand, the left sides of these curves vary in shape, owing to variations in the reluctance at this part of the cycle. Greater variations, therefore, occur in the instantaneous values of the counter E. M. F. induced in this part of the cycle than in the former part, with the result of increasing the form factor where the induction curves corresponding to the current curves are relatively low and broad, and of decreasing the form factor of the counter E. M. F. curves where the inductance curves are narrow and high.

Again, since the maximum peak of the effective E. M. F. curve is opposite in sign and position to the leading peak of the corresponding counter E. M. F. curve, and since the sum of these peaks must not be greater than the adjacent peak of the fundamental E. M. F. wave, we see that an increase in the form factor of a counter E. M. F. curve causes an increase in the form factor of the corresponding effective E. M. F. curve, and vice versa. That the changes in the form factor of the effective E. M. F. curves are approximately directly proportional to the mean width of the inductance loops, and inversely proportional to the amplitude of the inductance loops. These conclusions are amply sustained by the data presented.

The variations that take place in the value of the armature inductance when the load is increased, lead us to expect that there is a proportionally greater increase in the value of the counter E. M. F. as the current passes 2 amperes in value. An accelerated increase in the counter E. M. F. would have the effect of making the compounding proportionally greater, for it would add a proportionately greater amount of energy to the circuit, owing to the fact that although the amplitude of the counter E. M. F. is increased, its phase position remains practically the same. That a positive acceleration does occur in the rate of increase of the counter E. M. F. is true, and also, that this is followed by a negative acceleration. The value of the counter E. M. F. depends upon the intensity of the current, and increases as the current increases. It, however, does not increase at a rate that is proportional to the rate of increase of the average intensity of the current, for its value also depends upon the armature inductance which first increases to a maximum and then decreases, as is shown by the curves of Plate 10. We, therefore, find that as the average intensity of the arma-

ture current is uniformly increased, the counter E. M. F. experiences a proportionally greater rate of increase up to a certain point and that after this point is passed, its rate of increase is diminished.

This means that as the load comes on, the value of the effective electromotive force increases above the value of the fundamental wave for a time. For from the relative positions of the highest peaks of the curves B and C of Plate 11, it will be evident that any increase in the virtual value of the counter E. M. F. will cause the virtual value of the effective E. M. F. to increase also, and any increase in the virtual value of the effective E. M. F. above the virtual value of the fundamental wave of E. M. F. raises the potential at the brushes. The fact that the virtual value of the effective E. M. F. finally falls below that of the open circuit E. M. F is due to the ultimate gradual decline in the armature inductance wave and a consequent change in the form of the counter E. M. F. magnetization curve, which reduce the amplitude of the leading peaks and augment the amplitudes of the trailing peaks of the counter E. M. F. curves. This effect is apparent in curves D and E of Plate 14.

As exemplified in the curves of Plate 7, we find that the maximum induction threading the armature coils occurs when the form factor is least, and the armature inductance greatest. Again, the analysis of the forces involved shows us that the point F on the form factor curve of Fig. 6, and the point T on the "B & H curve" of Fig. 5, are intimately connected.

The double rôle played by the permeability of the iron of the armature core and pole-pieces, and the importance that may be attached to the permeability of the iron under favorable conditions is forcibly brought to our minds. We are enabled to see a little more clearly the complex relations of the interlinked forces that act and react upon one another in the conflict of the air-gaps, and there is established a basis for the analysis of a problem that has been more or less obscure.

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[ADVANCE COPY—SUBJECT TO REVISION.]

ELECTRIC METERING FROM THE STATION STANDPOINT.

BY CARYL D. HASKINS.

It has occurred to me that in presenting a paper to the INSTITUTE upon such a subject as that which I have selected, I may appear to have departed too entirely from the technical side of our profession and to have selected a line of argument which would have been more appropriate before a more commercial body. But in my opinion such is not the case, for I find that almost every merit, in, or objection to metering apparatus, or in connection with the use of it, is dependent upon some point involving engineering skill.

The general adoption of the electric meter is in itself an endorsement of the precise methods which characterize engineering practice. It is, indeed, a well established fact to-day, well borne out by data from widely separated portions of the country, that the average electric lighting station can do one-third more business with the same station capacity on a meter basis, than it could upon a contract basis, under what were nominally equivalent contract rates, netting at the same time the same revenue per light as formerly. In other words, it is apparently well established that 33⅓ per cent. represents the average wastefulness of average human nature in connection with the use of light.

In many central stations to-day, I find that, whilst managers are almost universal in favor of an exclusively meter basis, a large proportion are still in ignorance as to what qualities they should seek and what they should avoid in selecting a meter.

In response to an inquiry as to what merits in a meter are necessary to success, a common reply is, accuracy, durability, regis-

tration in a simple unit easily comprehended by the customer, and ability to withstand tampering, These points are probably of importance in about the sequence in which they are commonly stated; but they are too sweeping, too entirely generic and too slightly specific to be in any high degree helpful.

Let us, for example, consider the broad question of accuracy. A meter, which will be accurate under commercial conditions from quarter load to full load within $\frac{1}{10}$ of 1 per cent., or a meter which will *start* on 1 per cent. of its rated capacity, are neither of them necessarily either the most accurate or the best for general commercial use. This latter point is one which is frequently raised. The fact that a meter will start on 1 per cent. of its rated capacity is in reality no sure criterion of the accuracy of that meter, even on light loads. It is not necessarily even good evidence; yet I find that in very many cases this is almost the only test applied to meters at the time of purchase. The percentage of accuracy at light loads is very important, more important, I believe, than is commonly appreciated; but I am perfectly safe in saying, that a meter which will run within 5 per cent. of zero error on 5 per cent. of its rated capacity may readily be a much better meter, even though it will not run at all on 1 per cent. of its rated capacity, than one which will run on 1 per cent. of its rated capacity but in regard to which no evidence is at hand as to its percentage of accuracy at reasonably low loads.

Ability to start on very light loads is certainly an *indication* of merit and is important, but it is not nearly as important a point to determine as is the lowest load at which a meter begins to register with fair accuracy. I have inspected a very large number of meters which would start on phenomenally low loads and which would yet fail to give anything like approximate accuracy at reasonably low loads.

In considering the question of accuracy, therefore, the first two steps should be to determine the accuracy of the meter by actual measurements at full and medium load; and also at a reasonably low load; say, for example, 5 per cent. of the meter's rating.

That low load accuracy is really of vital importance is well shown by the fact, that with the average 24-hour station, in the neighborhood of 15 per cent. of the total station output goes to feed one and two lamp loads. Yet in the face of this I have seen large installations of meters reported as entirely satisfactory, tested with frequency and care under admirable systems, but only

at full or medium loads, and yet failing to account for more than 50 per cent. of the one and two lamp loads, or in other words, losing to the illuminating company an average of probably 7½ per cent of the revenue which their measured station output should give them, after deducting for legitimate losses.

Granting that, having determined the actual percentage of accuracy obtainable at light, medium and full loads, a very important and in fact probably the most important evidence as to accuracy has been obtained, there still remains much information of vital importance which should be sought and which should materially influence a decision.

One point which is very commonly neglected, but which is, nevertheless, quite essential, is the ability of a meter to give accurate results for brief periods on overloads. This is a point at which many meters fail, and it is also a point which, odd as it may seem, is intimately related to light load accuracy. It may be laid down as a rule, that in station operation the smallest meter which will do the work should always be used. Otherwise, however good the meter on light loads, much of the light load revenue must be lost in the effort to take care of occasional heavy loads. Extremely heavy loads are generally of brief duration, and on these loads a meter should operate with accuracy and also without injury to itself. This, therefore, should be an early point of investigation in selecting a meter.

On alternating circuits, inductive loads are becoming commoner every day. The wider use of fan motors and other alternating power devices, the rapidly growing popularity of alternating circuit arc lamps, and the commoner use of inductive dimmers, all render it essential that a meter should be accurate irrespective of the power factor. The company which insists upon charging its patrons for power delivered to fan motors on a basis of volt-amperes, is obviously rendering itself unpopular, greatly limiting its business and giving its competitor, or competitors, the best of opportunity for intruding; yet many such companies exist to-day, and they exist not because they are following a wise policy in their own estimation, but because they are ignorant of what they should look for in the meter which they are using.

Again, there are few electric light stations to-day of any considerable size and age which are not operating some smooth core and some tooth core alternating armatures. It is, therefore, important that the meters in service at such stations should be

equally accurate on any shape of wave; yet many meters fail in this particular; and seldom, if ever, is the point made a subject for investigation in selecting measuring apparatus.

This same consideration holds good in connection with frequency, and this is a point which it is difficult to overcome in most metering devices; but it is one which should be earnestly sought and which is of importance both to the station and to the consumer.

Even after this long list of points which must be investigated, as contributing to the broad question of accuracy, there are others which also merit consideration, but to a less degree. Such, for example, as barometric conditions (more especially altitude), temperature and humidity. These all have direct bearing upon the question and all enter into the every day conditions of central station practice.

Summing up the question of accuracy, we may say, therefore, that the following points should be investigated with care.

Ordinary volt-ampere accuracy;

Accuracy on inductive loads;

Accuracy on varying wave forms;

Accuracy on overload;

Accuracy on varying frequencies;

Influence on accuracy of variations of temperature, barometric conditions and humidity.

The second point, which is commonly given consideration in the selection of a meter, is that of life. This is a question which must depend more upon good judgment than upon any test which can be applied; for it is in reality no test of the enduring qualities of a meter to run it at excessively high speed for a relatively brief time. The life of a meter, in other words, cannot be measured by revolutions, irrespective of the speed of those revolutions; nor can it be determined by the speed at which it rotates alone.

Ninety per cent. of all the wear in a meter, centres in the case of motor meters at the single jewel bearing, which is almost universal. The two chief factors which have influence upon the mere mechanical life are the weight of the moving mechanism, and its speed, the variation of the area of the point of contact being, of course, always so small as to be out of the consideration.

A low speed meter is usually the best meter, provided the

speed be not carried so very low as to threaten the accuracy of the meter on light loads, by reason of being held up by intermittent friction in the form of dust or a spider. Practice has indicated that low speed is more conducive to long life than is light weight of the moving mechanism, although both are, of course, very important. More important than either, however, is the quality of the material used at the points of friction and the ease with which the friction parts can be renewed. The best of sapphire is barely good enough, and the pivot end must be of correct shape, burnished to the highest degree, and its point must be absolutely concentric with the centre of movement.

More than half of the meter jewels which are destroyed are rendered useless, not by the rotary motion of the shaft, but by reciprocating motion of the shaft, due to vibration. Hence it is very necessary that the jewels should be in some way cushioned, for vibration cannot be always avoided.

These are all, I admit, mechanical considerations, but they compass much of failure or success in electric metering. The purely electrical features of the meter contribute no grave factor of consideration in connection with the life question, always supposing that the copper is ample and the potential windings are so distributed and so ventilated as to preclude a burnout.

Passing over the central station man's third factor for consideration, that of the best unit of measurement, as one which is practically a closed question, we are brought face to face with his lamentable fourth point, the necessity that the meter should be able to withstand tampering. It is a regrettable fact, that this is a consideration which is coming daily into more prominence; but light has to be sold to all sorts and conditions of people; and apparently the transgressor against meters is even more common than the transgressor against taxes; and this is a growing evil, largely, perhaps, because of the lax conditions of the laws, which can be invoked to protect the meter owner in many of our states.

The methods which are commonly practiced in tampering with meters can scarcely form any proper part of a technical paper; but as this paper may go into the hands of some who need the knowledge to guard themselves and their interests, it can do no harm to briefly state the common methods used, not only that they may be guarded against, but also that meters may be selected which lend themselves least readily to such practices. It is not unusual to place large masses of iron above, below or at the side of

meters, but this practice is falling somewhat into disrepute among its advocates, since even they have in time discovered that there is a class of meter which it accelerates.

Electromagnets, drawing their energy from the circuits under measurement and used as the iron was formerly used, are now not uncommon, and it is difficult to prove in court deliberate evil intent.

Meter covers and bases are drilled and wires, broom straws and the like inserted. Covers are pried up and healthy colonies of spiders introduced.

Ingenious individuals have even been reported as finding profit in a clever apparatus for injecting fine iron filings into meters by means of a bellows.

All of these things need to be watched for and guarded against.

The question of installation and care of meters, is a wide subject, and in connection with it I shall endeavor to mention only a few salient points, selecting those which are most commonly overlooked or neglected.

The most radical cause of trouble in connection with installation is vibration and the consequent reciprocating motion of the shaft; for this reason the most solid of foundations should be selected, the neighborhood of moving machinery should be avoided, as should also partitions of light construction in which doors are located. The rhythmic vibration of moving machinery is infinitely more dangerous than occasional heavy shocks.

Meters should be installed as near to the foundation as possible, not as is now quite common, at the top of buildings, where the amplitude of all vibrations is of course much greater.

Locations where great variations of temperature occur are undesirable. For this reason also, basements are preferable to attics.

A very common error, causing the loss of very many meters annually, by the burning out of the potential circuits, occurs in connection with the metering of power delivered to motors. In the effort to save the very trivial amount of energy passing through a potential circuit, it is very common to instal meters on the motor side of the controlling switch. This not only exposes the meter to the full force of the field discharge, but it also results in the constant cooling and heating of the potential winding, and the resultant expansion and contraction chafes and weakens the insulation and also weakens the wire itself at the turns, opening the

path for a final breakdown either by a lightning discharge or by a field discharge.

As to care of meters. It is a fallacy to suppose, as many insist upon doing to-day, that meters should require no care whatever. Almost all meters will continue operative for a very long period without any care whatever; but the cost of a cleaning and testing visit twice annually is trivial as compared with the good results which follow such a system, by reason of the better light load accuracy obtained. It is not, I think, too strong a statement to say that such a system will have an influence for good, amounting to from 3 to 5 per cent. on the meter readings annually.

Central station managements have probable given more attention to systematic methods of meter reading than to any other one point contributing to success. The old and faulty plan of reading the dials of a meter at the time of the visit to the meter, is fast giving place to the better system, which provides the reader with a fac-simile of the meter dial in blank upon a page of his meter book. This fac-simile is roughly marked in pencil to indicate the position of the hand at the time of the visit. These fac-similes are taken into the office and are all read by one individual who is an expert in meter reading, and who sets down the consumption under the fac-simile on each page. Such a system commonly reduces the errors from about 10 per cent. per month where they not uncommonly stood under the old system, to materially less than 1 per cent. under the new; for surprising as it may seem, it is an extremely easy thing to make mistakes in reading meter dials.

In changing from the old and not infrequently popular contract system, a good many central stations in the earlier days made the grave blunder of going on to the new basis during the winter months, with the result that the highest bills of the year reached the customer after a long period of indulgence under the contract system, and the result at times proved temporarily disastrous.

Even to-day the pernicious influence of uniform bills the year through, which was created by the contract system, still lingers; and the proportion of customers who complain because their winter bills are materially higher than their autumn and summer bills is quite considerable.

It will be said that the explanation is sufficiently simple; but, unfortunately, however good and however simple the explanation, it has proved no simple matter to secure its acceptance and

credence. I have lately been much impressed by a system which has recently been adopted by a prominent Western company to at least partially offset this difficulty. During the months which are growing darker, they read their meters a day or two earlier each month, thus arbitrarily creating shorter months, whilst as the year progresses to the period of lighter days, the months are lengthened. This somewhat tends to even up the bill, is apparently quite as satisfactory to the customer, and is certainly entirely just and has created a very great falling off in the complaint list, for the character of the complaint keeps pace with the period of the year. Out of the hundreds of complaints which I receive annually, I find that by far the greater proportion in the summer are of slow meters and in the winter of fast meters.

I do not feel that I shall be doing justice to my subject, should I fail to make at least brief mention of the application of meters to the measurement of station output.

The gas companies to whom all central stations look for precedents, long ago found it imperative that they should have some means of determining just how much of their commodity they produced, and sent out through their mains. In all commercial enterprises it is difficult to satisfactorily guide and control a business, unless there be some positive means of determining how much of anything is produced; and it is surely just as important to all electric lighting companies to know how much of their commodity they manufacture as for any other concern. Until quite recently it has not been possible to obtain recording meters sufficiently large to care for the heavy outputs which are now so common, but such meters are now readily obtainable.

The value of a system of station meters must necessarily prove very great, since it furnishes an absolute check system upon coal and water consumption, and engine and dynamo efficiency. Whilst it also furnishes a ready means for comparison between station output, customers meter indications, line losses, leaks and grounds.

In closing, some brief consideration at least is due to the new fields into which meters are reaching, and to the help special metering features may perhaps give indirectly as well as directly, to the amplifying of the business of electric light and power companies and to their more economic operation.

There has recently been much interesting discussion regarding

the question of the flattening of the peak of the load either by the systematic modification of rates under special time contracts, governing the hours of burning, which does not concern the immediate subject matter of this paper, or by an actual modification in one of several forms in the meter itself, which should practically make the meter automatically control the modification of the rates in such a way as to gain the same end with certainty, as is aimed at in the special contract system.

Whilst personally I have grave doubts regarding the actual feasibility of this plan commercially, in view of other and perhaps simpler methods by which it can be accomplished, I still have much respect for all of the various methods which have been proposed and do not question that there will be at least many cases where they can be advantageously applied. Questions relating to the peak of the load, however, are subject to such great variations locally that a rule which would apply in New York might very readily fail in a system adopted in a smaller town.

It is quite obvious that the best double-rate meter will be that which tends to flatten the load curve of the station, not by oppressing or discouraging the user of light, who must have his light at the period of the peak, so much as by encouraging the use of light at other periods. We do not want to provide means for cutting off the peak so much as we want means for raising the rest of the curve to the same height as the peak. In my personal opinion, it is in this respect that perhaps the most ingenious of all these double-rate meters falls short. I refer to that form of two-rate meter which proportionately increases its rate of record at such time as the local load which it is measuring is highest. This discourages the use of light at the period of the local peak, and if the local peak and the station peak are co-incident, it absolutely fulfils its purpose. But if they are not it fails, because instead of discouraging the use of a large amount of light at the time of the local peak, it should actually encourage it. Encouragement of local peaks, which are not co-incident with the station peak, is beneficial to the central station in the highest degree, for it tends, as I have pointed out it should, to raise the general load curve towards the station peak magnitude.

If two-rate meters are to be used, therefore, I believe that their increased proportional speed should be dependent purely

upon the occurrence of the station peak, and should bear no relation whatever to the occuring of the local peak. Such an arrangement can be secured in a number of ways, all of them simple and all of them effective.

One other feature of metering, which has recently come into existence in Europe, is about to make its appearance commercially in this country. It brings with it much of promise for the increase of profitable business for central stations. I refer to the pre-payment meter system. The drop-a-nickel-in-the-slot and get-your-money's-worth-meter. In gas practice this system has proved an unqualified success. I am informed that the London Gas Light Co. added 6,000 new customers of a profitable kind over and above their average annual growth in a single year; and other companies have had similar experience.

There is in every large city a considerable area into which illuminating companies have been unable to go by reason of the untrustworthy character of the people who would there be their customers. In other words, because the people in these districts are a floating population without credit, coming to-day and going to-morrow, and yet ready and willing to buy electric light at high rates.

The pre-payment meter throws open this new field and makes it immediately available; and here I predict for it wide usefulness.

A paper to be presented at the 19th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 26th-28, 1887.

[ADVANCE COPY—SUBJECT TO REVISION.]

ELECTRIC TRACTION.

Notes on the Application of Electric Motive Power to Railway Service, with Illustrations from the Practice of the Metropolitan Elevated Road of Chicago.

BY M. H. GERRY, JR.

In the following paper will be found a brief discussion of some of the more important problems arising in connection with the application of electric motive power to the heavier classes of railway service. A number of tests and diagrams from the Metropolitan Elevated Railroad of Chicago, are introduced by way of illustration.

A part of this paper relates especially to the application of electric power to passenger rapid transit on elevated and suburban roads. The conditions for this service differ somewhat from common railway practice. Regular stops are made at frequent intervals; the distance between stations on elevated roads, for example, averaging about 2000 feet. The interval between trains is small, and the time of stops very short. The traffic is irregular, is heavy at certain hours, and is apt to increase and decrease at a rapid rate. To make the fast running time desired, the speed must increase up to the point where the brakes are applied; thus the maximum of speed is high compared with the mean speed. There is little or no opportunity for maintaining the speed, and the running time depends almost entirely upon the rate of accelerating and retarding of the train.

With a given number of stops per mile, the amount of power required will increase very rapidly with the speed beyond a certain point, and the cost per car mile will not furnish a reliable basis of comparison for the motive power of different roads un-

less the conditions are the same. A slight difference in the average speed, or in distance between stations may cause a considerable change in the amount of power required.

There are in operation at the present time several noteworthy examples of the application of electric motive power to the heavier classes of railway service. The most important of these installations are the Lake Street and the Metropolitan Elevated Roads of Chicago, the Baltimore Tunnel Line of the Baltimore and Ohio, and the Nantasket and Berlin lines of the New York, New Haven and Hartford Railroad. From the experience gained on these roads, there is no longer a question in regard to the ability of properly designed electric motors to operate trains of the heaviest weights in service, and at any speed permissible under practical railroad conditions. In the future, matters of efficiency and general utility must determine the desirability of electric power for any particular railway service.

Certain operating conditions have a special bearing on the efficiency of this form of motive power; the most important being the frequency of the train service. If traffic is such that a large number of trains must be operated on a division, the electric power will have an advantage in point of economy, over steam locomotives; and if the trains are few, the reverse will be the case. This condition holds good independently of the weight of the trains or of the speed attained. The length of the line is in itself no bar to the successful operation of an electric railway system, as, by using alternating current apparatus. the power stations may be located favorably, and at long distances apart.

The distribution of the current to the trains, while it presents many practical difficulties in detail, is not so serious a problem as it was thought to be at one time. Of the three systems of over-head conductor, conduit, and third rail, the last has given the best results, and is advisable wherever the conditions are such that it can be installed. For roads operating on their own right of way, there is really no serious objections to the third rail, and all of the difficulties encountered at crossings, switches and in yards can be overcome by methods already in use on the roads named above, or by other devices that have been proposed. It is not to be expected that all details of such a system are in an entirely satisfactory and final form, but they are practically operative at present and being constantly improved as difficulties

develop in service. The experience already gained also justifies the statement that a reliable overhead or conduit system for heavy service can be constructed if the conditions favor the use of such methods.

The Metropolitan Elevated Railroad.

This system, now in its second year of operation, is the largest road in existence employing exclusively electric power for a heavy passenger service.

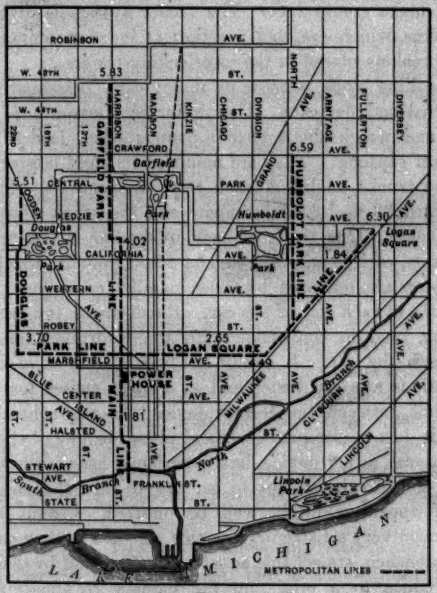


Fig. 1.

The structure has four tracks, from Market street west to Marshfield avenue, at which point three double track lines diverge. The northerly branch divides again near Robey street into two double track branches. From Market street to each of the terminals, the distance is about six miles. (See map, Fig. 1).

Current is conveyed to the trains by the third rail system; the "trolley rail" being placed $20\frac{1}{8}$ inches outside, and $6\frac{1}{4}$ inches

above the running rail. It is of the common "T" section, bonded with leaf copper bonds, and divided into sections to provide for expansion. The insulation for the third-rail, on all but a small section of the road, consists of hardwood blocks, mounted on small iron chairs fastened to the ties. On a recent extension an improved form of insulation made of stone-ware has been tried with success. The electric leakage is small at all times. In dry weather it is entirely negligible and in wet weather is never more than a few amperes. It is greatest after a dry season, when the first shower is washing the accumulated iron dust from the insulating blocks. Steel rails are used for feeder, and copper only to make connections. The feeder system is divided into six sections, which are tied together at junction points through circuit breakers placed in the interlocking towers.

The rolling stock consists of motor cars, passenger cars and a few coal and flat cars. The motor cars measure 47 feet in length and weigh about 62,000 pounds when loaded to their maximum capacity. They are mounted on rigid bolster locomotive type trucks, having 33-inch steel tired wheels. The truck centers are 33 feet 6 inches apart and the truck wheel base 5 feet 6 inches. One truck of each motor car is equipped with two motors, each nominally rated at 2,000 pounds drawbar pull. The motors are operated by series parallel controllers, situated in the cabs at each end of the car. Rheostats of the packed ribbon type, used in connection with the controllers, are placed underneath the car. A circuit breaker placed in each cab is used both as a safety device and as a main switch for opening the circuit between the trolley device and the controller. A main fuse box is also provided, and placed in one of the cabs as an additional safety device, but experience has shown that failures of the circuit breaker to act are so rare, that the former piece of apparatus might well be omitted. Circuit breakers have proven very satisfactory for this service, as they cost little for maintenance, are reliable as safety devices, and by their quick action reduce to a minimum the damage to apparatus from grounding and short-circuiting.

The cars are warmed by electric heaters arranged in three circuits, two of which take about seven amperes each and the remaining circuit about four amperes. All of the heaters are required only in the coldest weather, and are turned on and off by the trainmen. By cutting out all or part of the heaters for

a short time when the traffic is heaviest, the peak of the load can be reduced and the heaters used to improve the load factor.

The air-brakes are of the direct or "straight" air type with an additional re-enforce cylinder. The air is compressed to 60 pounds by a vertical pump, driven by a motor of about three horse power. The pump motors have automatic control, regulated by the air pressure and also hand control from each end of car. The pump with its motor and automatic controller is placed in one of the cabs.

The passenger cars are 47 feet in length and of the standard pattern, in use on all elevated roads. They are mounted on swinging bolster trucks, having 30-inch wheels and when loaded to maximum capacity weigh about 46,000 pounds. Two, three, and four car trains are in service at different hours, corresponding with the traffic. About 1,200 trains are handled daily and under very close headway out of Franklin street terminal.

The power house is supplied with water tube boilers, mechanical chain stokers, coal and ash handling machinery, forced draft, automatic oiling system and all modern appliances. The boilers are 14 in number and work at 165 pounds pressure. There are four vertical cross-compound engines, direct connected to the electric generators. The condensing water is taken from the Chicago river by tunnel, and water for the boilers from the city mains. There are four electric generators, two of 1,500 kilowatt and two of 800 kilowatt capacity. The switchboard is placed on a gallery and is provided with the usual instruments, including recording wattmeters for each generator. There are six feeder panels corresponding to the divisions of the feeder system.

The Power Absorbed by Trains.

In an electric railway system, the mechanical energy supplied at the engine shaft may be divided, for purposes of discussion, into two general classes. First, that finally absorbed or utilized in propelling the train, and, secondly, the energy lost in transformation and transmission, including losses in generators, line, rheostats, and motors.

The first division or class, that is, the energy to propel a railway train, may be divided again into three parts: First, that required to overcome inertia and accelerate the train to its maximum speed after each stop. Secondly, the energy required on account of ascending grades. Thirdly, that required to over-

come train resistance; including friction, air resistance, etc. If the stations are far apart, the energy required to accelerate the train may be neglected without serious error, but for a service where trains make frequent stops, and the maximum speed is high, compared with the mean speed, it becomes of importance, and may easily be the greatest of all losses. The amount of energy required for train acceleration, obviously depends upon the number of stops, the train weight and the maximum speed. Knowing these quantities, it can be readily determined from the common mechanical formula for kinetic energy. $U = \frac{w\,v^2}{64.4}$

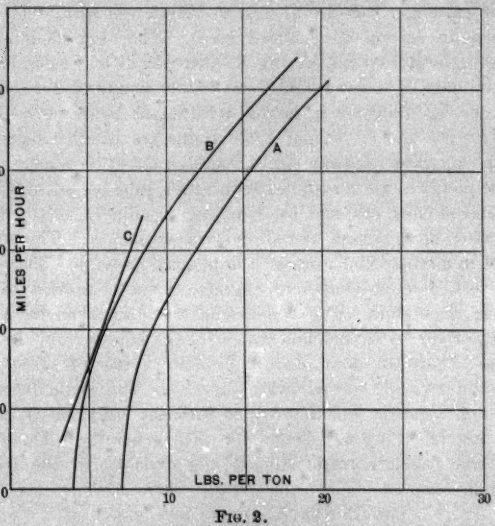


FIG. 2.

The horizontal effort or drawbar pull required to produce a certain acceleration in a given time may be obtained from the mechanical formula. $f = \frac{w\,v}{32.2\,t}$.

The work done in ascending grades is the product of the train weight and the vertical distance the train is lifted. The horizontal effort required to take a train up a grade is equal to the product of the train weight by the per cent. of grade.

Train resistance, as used in this paper, includes all retarding

forces other than those due to inertia and grades. Formulas for determining this quantity are empirical and are based upon experimental results, where the conditions have varied widely. D. K. Clark, in "Railway Machinery," recommends a formula

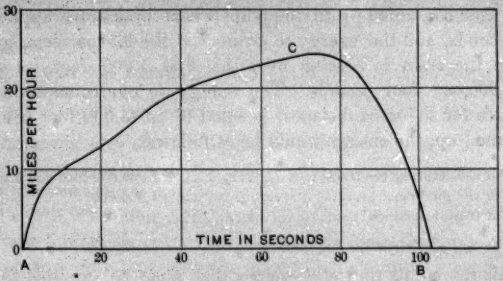


FIG. 3.

which, reduced to tons, of two thousand pounds, becomes $R = 7.1 + \frac{v^2}{192}$. Another formula in use is $R = 4 + \frac{v^2}{200}$, where R = resistance in pounds per ton of train weight, v = speed in miles per hour. These two formulas have been plotted in Fig. 2, and are marked respectively A and B. From measurements taken on the Metropolitan Elevated, the curve C has been determined and is used in the following discussions.

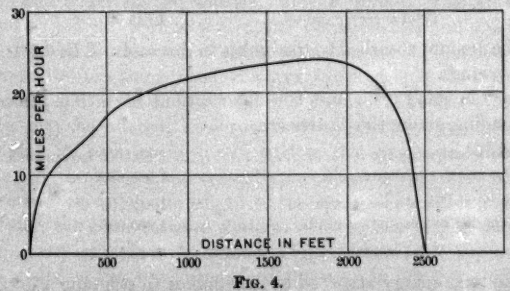


FIG. 4.

In Figs. 3 and 4, are shown actual speed curves on a time and a distance base, for a train running between stations, 2,500 feet apart. For the purposes of discussion, consider the train weight as 100 tons and in the first case assume it to be on an ascend-

ing grade of ½ of 1 per cent. From the curves, the speed at the time brakes are applied is 24 miles per hour, and the kinetic energy at that speed, for the train, is 3,800,000 foot pounds. The time consumed up to the point where brakes are applied is 77 seconds, and the energy to overcome the 0.5 per cent. grade while the train is passing over the first 1,900 feet, is equal to 1,900,000 foot pounds. The energy to overcome train resistance for the same distance, is equal to 1,045,000 foot pounds. Summed up, the energy would be as follows:

For accelerating the train	3,800,000	foot pounds.
For the grade	1,900,000	" "
For train resistance	1,045,000	" "
Total energy required	6,745,000	" "

This represents the total energy that must be supplied to the train from the time of starting, up to the moment the brakes are applied. From this point, the acceleration is negative, and the kinetic energy of the train is absorbed by train resistance, the grade and the brakes. The amount taken up by the brakes is 2,900,000 foot pounds.

The above case is for the train on a 0.5 per cent. ascending grade. For the train on a level the figures would be as follows:

For accelerating train	3,800,000	foot pounds.
For train resistance	1,045,000	" "
Total energy required	4,845,000	" "

The amount absorbed by the brakes in this case will be 3,500,000 foot pounds.

For the same train and speed conditions for a 0.5 per cent. descending grade, the figures are,

For accelerating the train	3,800,000	foot pounds.
For train resistance	1,045,000	" "
Total energy required	4,845,000	" "
Supplied by descending grade	1,900,000	" "
Total external energy required	2,945,000	" "

The total energy absorbed by the brakes in stopping the train in this case is equal to 4,100,000 pounds.

The foot pounds per ton mile in each of the cases cited are as follows:

On an ascending grade	142,000	foot pounds.
On a level	102,000	" "
On descending grade	62,000	" "

The average speed taken from the curves in the cases cited is 16.5 miles per hour, not including stops. Allowing twelve seconds for a stop, it is fifteen miles per hour.

The average rate of using energy or the power, allowing time for stops, is as follows:

On a .5 per cent. ascending grade	106.5 H. P.
On a level	76.5 "
On a .5 per cent. descending grade	46 5 "

The power may also be divided as follows:

For accelerating the train	60 H. P.
For ascending grade	30 "
For train resistance	16.5 "

These figures do not, of course, include losses in applying the power, and only represent the energy which must be applied at the rails to produce the results in the special cases named above. The conditions vary widely at times on the same road, but the above examples may serve to show how great is the percentage of power required to accelerate the trains when the stops are frequent.

In a speed curve with a time base, such as Fig. 3, the area enclosed is proportional to the distance travelled. That part of the area enclosed by the curve from B to C, a perpendicular from the point C, and the base line, depends on the form of the braking curve and hence on the efficiency of the brakes. The area enclosed by the curve from A to C, the perpendicular and the base line, depends on the form of the accelerating curve. The distance between stations being fixed, the area enclosed must be constant and independent of the form of the curves. The shape of the curve may be altered, however, in two general ways, first, by changing its form so as to still enclose the same area, with the same length of base, and secondly, by altering the form of the curve and changing the length of the base. This latter change will alter the time between stations, while either of the changes may or may not affect the amount of power used, this depending principally on the maximum speed attained. In Fig. 5, the curves A and B represent equal distances passed over in equal times, but the energy required for curve A is materially less than for curve B. The amount of power required in any case will depend largely upon the form of the speed curve, that is, upon the rates of accelerating and retarding of the train, and it is always desirable to keep the maximum speed as low as possible. Motors

efficient at high speed are sometimes wasteful of energy because of insufficient torque, at starting and at low speeds, to produce a good form of acceleration curve.

The train weight may be considered as made up of two parts, the live, or paying load, and the dead load, which includes the weight of rolling stock, motors, etc. As the amount of power required by the train varies almost directly as the weight, it is desirable to have the non-paying or dead load as small as possible. In order that there may be sufficient traction, a separate locomotive must weigh between four and five times the maximum drawbar pull required by the train, all of which is dead load, in addition to that of the cars. It has been stated that a rapid acceleration is desirable if there are many stops, but as each pound of increased

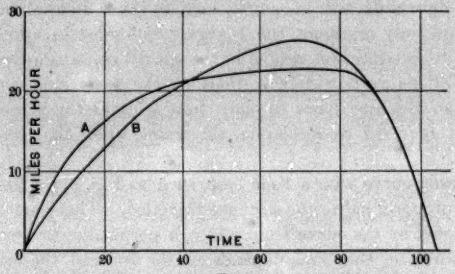


FIG. 5.

maximum drawbar pull from a locomotive must add four or five pounds to the dead weight of the train, a point is soon reached where no further advantage is obtained by increasing weight on the drivers and drawbar pull. The weight admissible on the locomotive driving wheels, on account of track and structure, also limits the amount of traction, hence the drawbar pull and rate of train acceleration. Thus, for a service combining high speed and many stops, there are advantages in a form of motor which may be so placed as to utilize a part of the car weight and live load, for purposes of traction. The cars should weigh as little as possible so as to reduce the total dead weight of the train, for it is well known that the ton-miles of paying load form only a small percentage of the total ton-miles moved. On elevated roads it is probably below six per cent. on the average and on some roads, below one per cent.

It is hoped that these remarks may direct attention to the question of economy in the use of power or to what may be called train efficiency, in contradistinction from the efficiency of the apparatus used in the generation and transmission of the power to the car axles. This latter subject will now be considered.

The Motors and Controlling Apparatus.

At the present time, direct current series motors with series-parallel controllers are in all but universal use for electric railways. Shunt motors are in service in Europe to a limited extent, and alternating current motors have been given a trial. The latter have advantages under certain conditions for lines of considerable

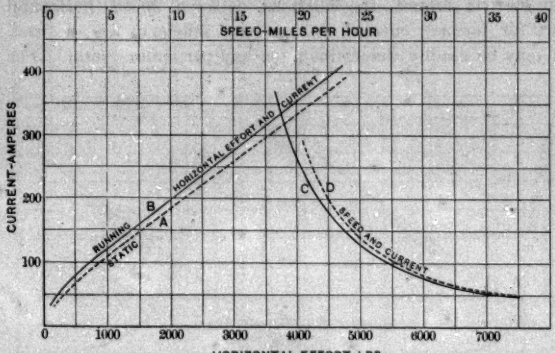


Fig. 6.

length where there are but few stops. Alternating current motors tend to run at a nearly constant speed, approaching synchronism, and do not regulate with the same facility and efficiency as direct current motors. They develop, however, a good starting torque and may even produce a better form of torque-speed curve than the common series motors. The double conductor required with alternating current motors is an objection, but there are many advantages in their favor; the system is untried and its possibilities are not fully known.

The characteristics of the motors in use on the Metropolitan Elevated are introduced in this paper rather than a general discussion, and it is hoped that this will be acceptable. By modifying the design the relations existing between the torque, speed,

current and voltage, may be varied within wide limits, but the general relations are always the same and are well illustrated by the diagrams below. All modern railway motors are much alike, the designers having been forced by the conditions imposed upon them, into practically one general type of machine. The requirements are a large output, ability to withstand heavy overloads, freedom from sparking, a low rotative speed, light weight and limited space. The result is the cast-steel multipolar motor, operating with nearly saturated fields and high magnetic densities in the armature.

In electric motors, the relations between speed, horizontal effort (or torque), current, voltage, and efficiency are all fixed, and may be readily determined for any particular motor. For

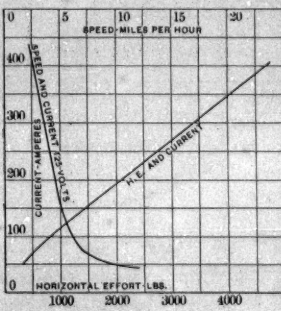


Fig. 8.

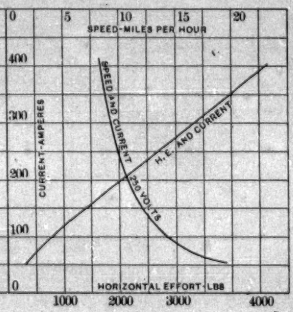


Fig. 7.

most practical purposes it is best to represent these relations graphically. At A, in Fig. 6, the relation between current flowing and the static horizontal effort produced, is shown for the standard motors in use on Metropolitan Elevated Road. Curve B, in the same figure, represents the horizontal effort produced when the motor is running with 500 volts at the terminals and at the speeds shown by C. The horizontal distance between A and B, represents the loss in horizontal effort due to friction and core losses. Curve D, in the same figure, gives the speeds which the motor would attain under the conditions named if there were no internal resistance, and the horizontal distance between the latter curve and C, represents the loss in speed due to such resistance. Thus the losses in a series motor may be divided

into two classes, those that lessen the torque and those that reduce the speed. In Figs. 7 and 8, the relations between current, speed, and horizontal effort are plotted for the same motor at 250 and 125 volts. The static horizontal effort is the same in all cases, but the running horizontal effort is slightly greater for the same current at the lower voltages, because the losses which affect it are less at the lower speed. At the same time the percentage of loss due to internal resistance becomes greater, as it depends upon the current flowing, while the total input of energy varies with the electrical pressure as well; hence, the reduced efficiency at the lower voltages. Curves of efficiency, in relation to the current, are plotted in Fig. 9, for the same

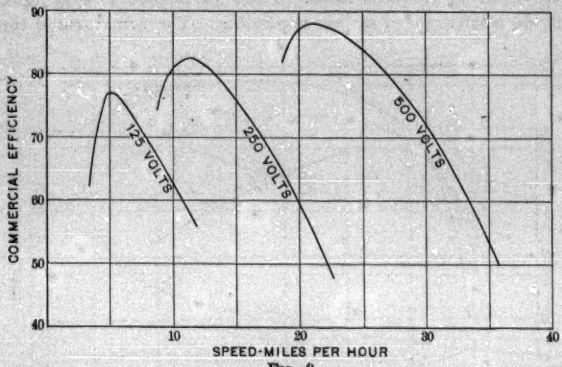


FIG. 9.

voltages. In Fig. 10, the efficiency is plotted to the speed, and it will be seen that the curves fall off rapidly above or below a certain narrow range of speed over which the efficiency is high, at any one voltage. There is a considerable range of current and horizontal effort, over which the efficiency is high, as can be seen from Fig. 9, but it corresponds to only a small speed variation. The relations of speed to horizontal effort are given in Fig. 11. The maximum working range of the motor is from 350 to 4,000 pounds horizontal effort, and the total speed variation on this range at 500 volts will be about 14 miles, and at 250 volts, about 10 miles. The range of speed obtained in service at any one voltage is practically about one-half this amount, and if 250 and 500 volts be considered as the pressures

at the motor, in series and parallel combination, then the total range of speed, without further alteration of the voltage by resistance in circuit, will be about 12 miles over a total speed range of 34 miles. For each combination of motors in series parallel, there is a certain range of speed over which the efficiency is equal to that of the motors; but at all other speeds, resistance must be introduced in circuit and the efficiency is reduced.

The weight of the armature and other revolving parts is a feature of importance in motors designed for a high-speed service, requiring frequent stops. These parts should be as light, and the rotative speed as low as possible. The armatures of the

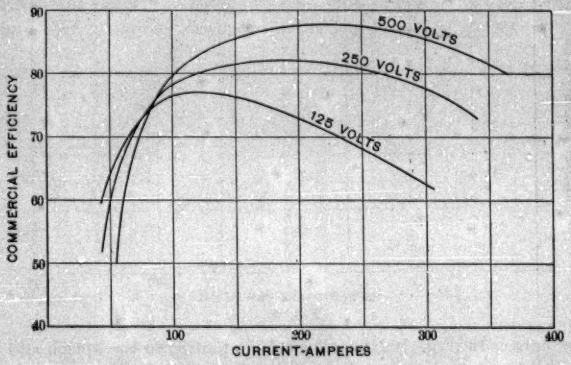


FIG. 10.

Metropolitan motors weigh approximately 1,400 pounds and are 18½ inches in diameter. At 800 revolutions per minute, corresponding to 25 miles per hour, the kinetic energy in each armature is equal to 43,000 foot pounds. Thus, for a two motor equipment, 86,000 foot pounds of energy are dissipated each time the car is stopped from a speed of 25 miles per hour. This amount of energy will vary with the square of the maximum speed and if stops are frequent, it becomes an appreciable loss.

The average load a motor is capable of sustaining is fixed by the permissible increase in temperature. The amount of such increase will depend on the average load, the efficiency of the motor and the extent and character of the heat radiating surfaces.

The actual load on a railway motor differs at times, very widely, from the average load and ability to withstand these fluctuations, will depend in part on the heat storage capacity of the motor. The metal acts, to a considerable extent as a reserve of heat, receiving it when the motor is doing its heaviest work and giving it up at lighter loads. A glance at the load diagrams in the latter part of this paper will serve to show how great these fluctuations may be under certain conditions. The amount of heat radiated

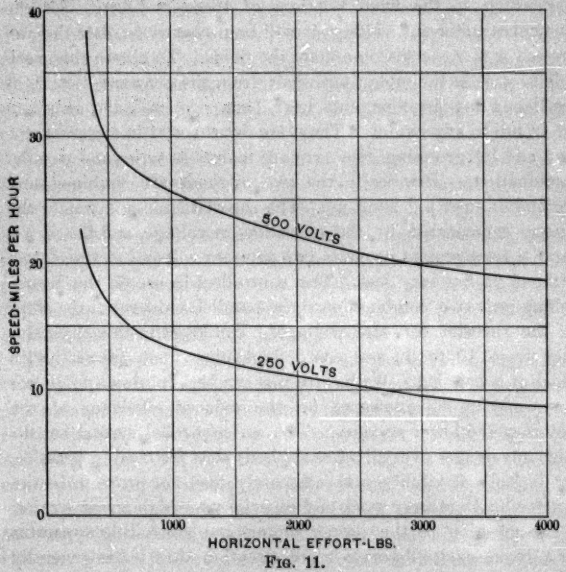


FIG. 11.

in a given time varies greatly with the speed of the car and the temperatures. With the air at 60° F., and under average working conditions, a Metropolitan motor will radiate heat at the rate of about 650 British heat units per minute. This is equal to 15 horse-power, corresponding about to 60 horse-power of loading. But these motors will readily withstand for a considerable period of time a loading of three times this amount. Most of the heat produced by this additional loading must be stored in the metal of the armature and frame. A considerable part of the

heat is generated in the armature, but its thermal capacity being nearly 150 heat units per degree, a large amount of heat energy can be stored before the temperature reaches the danger point. Slow speed armatures in general have more metal in them, and are thus better able to stand a variable load.

The speed of a series railway motor at any given impressed E. M. F. is fixed by the total resistance of the train. The horizontal effort developed must just equal the resistance, or the velocity will change; therefore, if it be desired to maintain a constant speed, or to vary the velocity in any manner not corresponding to the fixed relations of speed and torque for the particular motor and voltage, it will be necessary to alter the impressed E. M. F., or to commutate the fields. To obtain this variable E. M. F. at the motor terminals from the constant E. M. F. of the line, many arrangements have been proposed, but only two are in use to any extent. They are by rheostat in the main circuit, and by grouping two or more motors in series and parallel combinations. Practically the two methods are combined, and are now in nearly general use. The rheostatic method wastes the energy represented by the reduction in voltage, and the series-parallel arrangement provides two or more voltages at the motors without preliminary loss. The controllers in use on the Metropolitan are two combination series-parallel and have three steps on the rheostat for each voltage. The losses in this apparatus vary from 10 to 20 per cent., depending upon the skill with which it is handled. With care this can be kept down to 10 per cent., making no allowance for the reduced efficiency of the motors at the lower voltages. The series-parallel system has decided advantages over all other methods thus far tried in practice, but it lacks flexibility and ultimately may not prove to be the best for heavy railway work and especially for high speed service.

The selection of the proper motors and controlling apparatus for a given service deserves more attention than it has generally received. The horse-power and maximum speed have too often been the determining quantities. A rating based on horse-power is now understood to be of little value, and the maximum speed of which a motor is capable may be of still less account as representing its performance with a train. Quite generally, motors have been speeded too high, the result being insufficient starting torque, a poor commercial efficiency and less average speed than a better selected motor would have developed.

The Generators and Feeder.

Anything like a complete discussion of modern railway generators or of the problems connected with railway feeders, might well be the subject of a separate paper. It is designed here simply to touch upon a few points relating to the general system.

Railway generators at the present time are nearly all of a direct current type, but there is reason to believe that in the future two and three-phase alternating current machines will be installed. The development of the rotary transformer will be largely responsible for this change in practice. Power stations can be more favorably located in respect to fuel and water supply, and through sub-stations furnish power to larger areas. With this change will come also greater economy in the production of power, which cannot but have a favorable effect on the development of the electric railway.

The commercial efficiency of railway generators varies from 90 to 95 per cent. Under favorable conditions, the average or "all day" loss for large direct connected machinery (units of over 600 K. W.) is about seven per cent. Direct connected alternating current generators give about the same efficiency as direct current generators. Commercially, the best results are obtained with a few units of large size. It is unnecessary and poor practice to install many small units for railway work.

The load line of an electric railway is subject to two kinds of fluctuations; first, those sudden changes caused by the starting together of a number of trains, and secondly, the more gradual change due to the variation of traffic at different hours of the day. On roads operating but few cars, the fluctuations due to the first cause are of considerable amount, but on large systems with many cars the changes in loading from starting up of trains are very slight—hardly noticeable, in fact—and this is especially the case if the feeders are tied together and form a network. There still exists, however, the change in the load line corresponding with the traffic. A railway load line differs from that of a lighting station in having two nearly equal "peaks" or points of maxima, one in the morning and one in the evening. These variations are best taken care of by cutting in and out units, while the momentary changes can usually be cared for by a slight overloading of the machinery. Engines and generators for railway purposes have a good efficiency over quite a wide range and generally stand overloads very well. In Fig. 12 are shown seven load curves from the power station of the Me-

tropolitan Elevated. The curves correspond to the days of the week and indicate the average power taken, but do not show momentary fluctuations, caused by the movement of trains. The chief characteristics of these curves are the two decided "peaks" ocurring daily with great regularity. The peaks vary as to amount and time, with the season of the year, and to some extent with the weather, but are always present in a marked degree. Street railway systems with many lines extending to different parts of a city, usually show a station load with less decided and broader peaks. This is due in part to the habits and occupations of the

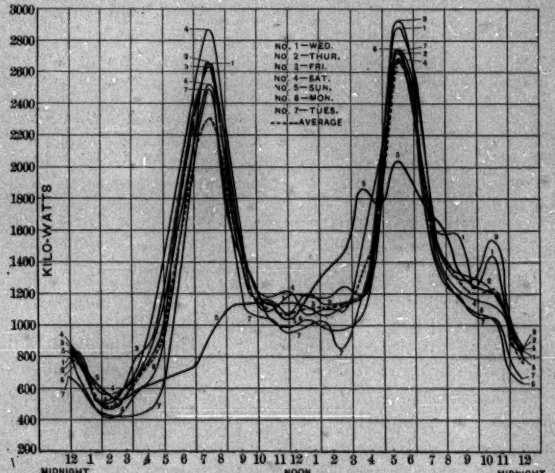


FIG. 12.

patrons of the various lines which determine the hours of maximum traffic. When combined, the load curves from a number of such lines will give a more favorable station load than any one line or group of lines in the same section of a city.

The load curves of the Metropolitan have proven to be a very sensitive index of the traffic. A delay on the competing cable lines or increase of travel from any cause is at once noticable in the power house. The greater station loading is due not so much to the increased weight in passengers carried, as to the longer stops necessary to discharge and to take on passengers; thus requiring a higher speed to keep the trains on time.

The feeder system has an effect upon the form of load curves as well as upon the total amount of energy required. The highest percentage of loss will occur at the moment of greatest loading, but this rarely takes place at the same time on different sections, and an advantage is obtained by connecting the lines together to form a net work as far as possible. Feeders are usually divided into sections as a matter of safety and convenience. The best economy of copper and of power, and the most favorable load lines are obtained when the number of such sections are as few as consistent with the safety and flexibility of the system. When feeder sections are connected, the best practice calls for a fuse or circuit breaker in this circuit. The permissible percentage of loss between the power house and the trains, is partly a commercial question, depending on the cost of power, and interest on the feeder investment. Transformers, rotary converters, boosters, batteries, and similar apparatus forming a part of the feeder system, should be considered with special reference to cost, operating expense, all day efficiency and effect on the load factor of the generating station.

The Efficiency of Transmission.

The energy dissipated between the engine and the car axles may be divided into three parts, that lost in the electrical generators, the losses in the transmission lines (including transformers, rotaries, etc.) and the losses in the car controlling apparatus and motors.

The amount of loss in the generators will depend upon their efficiency and average loading. Modern railway generators have good efficiency above half load, and in stations designed with reference to the load line, there is but little difficulty in keeping the machinery above three-quarters at all times. In the table below are given the efficiencies for a number of direct connected machines of modern design.

TYPE OF MACHINE.	COMMERCIAL EFFICIENCY.			
	Full load.	¾ load.	½ load.	¼ load.
D. C. Generator, 700 K. W	94	93	92	—
D. C. Generator, 750 K. W	93.5	92.5	91	85
D. C. Generator, 800 K. W	96	95	93	—
D. C. Generator, 1,500 K. W	94.5	94	93	—
A. C. Generator, 750 K. W	94	93	91	—
A. C. Generator, 600 K. W	93.5	92	87	82
A. C. Generator, 700 K. W	94	93	90	83
A. C. Generator, 650 K. W	93.5	91.5	89.5	—
Rotary transformer, 650 K. W	94	93	90	—
Rotary transformer, 600 K. W	95.5	92.5	90	84

With machines of this type and size, the all day efficiency ought to be about 92 per cent. A sub-station provided with rotaries and static transformers working under a good average loading, should have an efficiency of about 89 per cent.; a loss of 8 per cent. in the rotaries and 3 per cent. in the transformers. The sub-station apparatus is at its highest efficiency at the time of greatest loading, when the feeder lines are at the lowest efficiency and thus have a favorable effect on the load line.

The losses on railway feeders vary from 10 to 25 per cent. Often there is sufficient copper if rightly distributed and tied together to reduce this at least one-half. Such a change would also improve the load factor and increase the efficiency of the station. The losses in the motors and car apparatus have already been referred to in this paper, but actual data and tests are here introduced in evidence.

From a large number of tests made on the trains of the Metropolitan Elevated Road, the following have been selected as illus-

No. of trip.....	1	2	3	4	5	6	7	8
No. of cars in train	4	4	4	3	3	2	2	4
Total time of trip..	28′26″	29′03″	28′30″	28′37″	27′26″	25′30″	23′48″	32′44″
Total time of stops.	2-19	2-05	2-42	1-47	1-16	0-54	1-22	1-41
Time running.....	26-07	26-58	25-58	26-50	26-10	24-36	22-26	31-03
Average speed (including stops)....	13.3	13.0	13.2	13.88	14.4	14.9	15.9	11.53
Average speed (not including stops)..	14.4	14.0	14.5	14.7	15.1	15.3	16.8	12.2
Average current (ineluding stops).	138.3	142.6	138.6	130.2	129.5	90.1	106.6	101.1
Average current (not including stops).....	148.7	153.2	151.8	137.4	135.6	92.5	119.4	106.4
Average volts (at the train).....	504	498	503	512	516	521	529	509
Efficiency from generators to car axles.....	51	50.5	52	50	51	51.5	50	47.5
Kilowatt hours per car mile (at the train).....	1.32	1.36	1.32	1.69	1.62	1.58	1.76	1.11
Kilowatt hours per car mile (at the station).....	1.44	1 52	1.44	1.81	1.68	1.67	1.69	1.21

trating this part of the subject. The trips are numbered from one to eight, and in the table below the data for each trip are given, together with the general results obtained. All of these

runs were made on a dry track, in moderate weather and under average working conditions. The total electrical energy at the train was measured by Thomson recording wattmeters and the voltage and current by Weston instruments. The velocity record was taken from a Boyer speed recorder and the stops and average speed from a double set of stop-watches. The pressure at the station was measured by a recording voltmeter.

Trip No. 1 was made from Franklin street over the Logan Square line with a four-car train, heavily loaded, making an average running time of 13.27 miles per hour. The maximum grade on this line, going west, is 0.75 per cent. ascending for about 2,350 feet, and descending for about 1,950 feet. Other grades do not exceed 0.03 per cent. and only extend short distances. Current and speed diagrams on a time basis are plotted in Fig. 13 for trip No. 1. The current is the total amount taken by the train for power, and an inspection of the diagram will readily show the point of passing from series to multiple. The amount of energy required or absorbed by the train is as follows:

Total energy for accelerating the train	30,940,000 ft. lbs.
Total energy for train resistance	14,110,000 ft. lbs.
Total energy for grade	3,400,000 ft. lbs.
Total energy required for propelling the train	48,450,000 ft. lbs.
Per cent. of energy for accelerating	63.9.
Per cent. of energy for train resistance	29.1.
Per cent. of energy for grade	7.0.
Time of trip, including stops	28 min. 26 sec.
Average H. P. required for propelling train	51.5.
Average amperes of current	138.25.
Average volts at train	504.
Average watts at train	69,678.
Electrical horse-power transmitted to the train	93.4.
Average volts at the station	545.
Average watts at the station	75,346.
Electrical horse-power at the station	101.
Efficiency from electrical generators to car axles	51 %.

Assuming the commercial efficiency of the generators as 93 per cent, the total power required at the engine shaft, to propel this train, is 108.5 horse power.

Trip number 2 was made with a four-car train, under similar conditions to trip number 1. A current curve on a time basis is given for this trip in Fig. 14. In all of the current curves, it is easy to distinguish by inspection when the motors are in series

and when in multiple. The stops on the controlled are also distinguishable by the greater peaks on the curves. The smaller peaks and other irregularities are due, principally, to changes in voltage, caused by other trains in the same section, taking more or less current.

Trip No. 3 was made under similar conditions to trips 1 and 2, and the data and results are given in the table.

Trip No. 4 and 5 were made with heavily loaded three-car trains and the results are set forth in the table. Both the speed and commercial efficiency of apparatus are higher than in the case of the four-car trains. A diagram of current on a time basis for trip No. 4 is given in Fig. 15, and a speed curve on a distance basis in figure 18.

Trips No. 6 and 7 are with two-car trains and show a higher speed than attained in the case of the three and four-car trains. The greater amount of power consumed in trip 7 is due, mainly, to the increased speed over trip 6. A current curve for the latter trip is shown in Fig. 16, and a speed curve in Fig. 17.

Trip No. 8 was made with four loaded cars and the motors operating only in series. Both the speed and current are less than for similar trips with the motors operating in series and multiple. The percentage of power saved is greater than that of the reduction in speed, but this is due, not to a better efficiency of the apparatus at lower speeds, but to the fact that the amount of power required to propel a train making many stops, decreases more rapidly than the average speed. The current diagram for the trip is given in Fig. 17.

The amount of power lost in the machinery and line, as indicated by the commercial efficiency of the apparatus given in the table, might seem at first thought to be large, but considering the transformation and the distance of transmission, it is certainly not excessive. The loss in this respect is offset by the smaller cost of producing energy by power-house methods. The train weight also may be reduced with electric power to a point impossible with steam locomotives, and the rate of acceleration increased, and thus a saving effected in power used at the train. While this does not improve the efficiency of the transmission, it reduces the total amount of power required, and as a feature of the system, it should be given due credit.

Electrical energy can be produced in the vicinity of Chicago, with cheap coal, under the conditions of a railroad load, at less

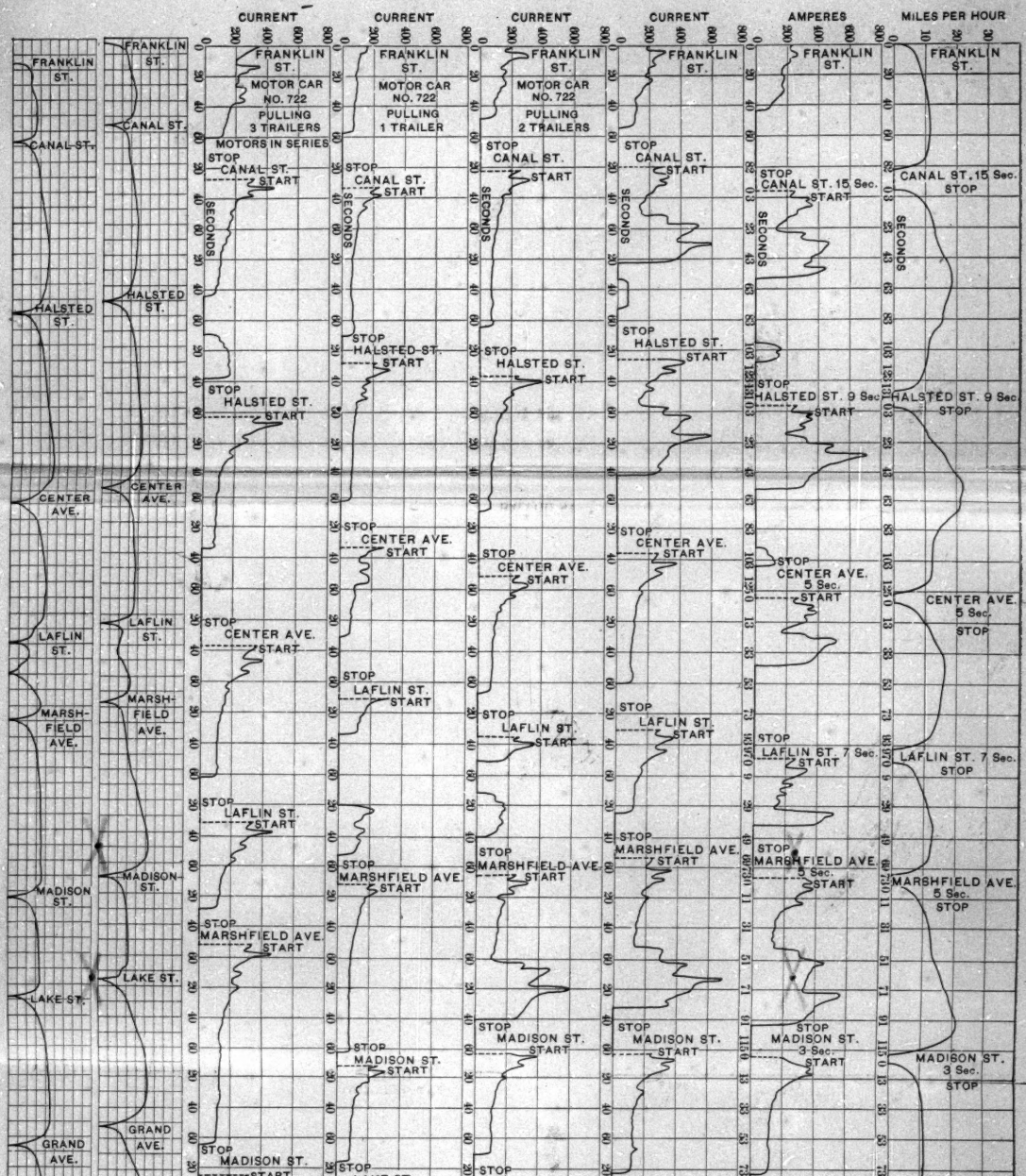
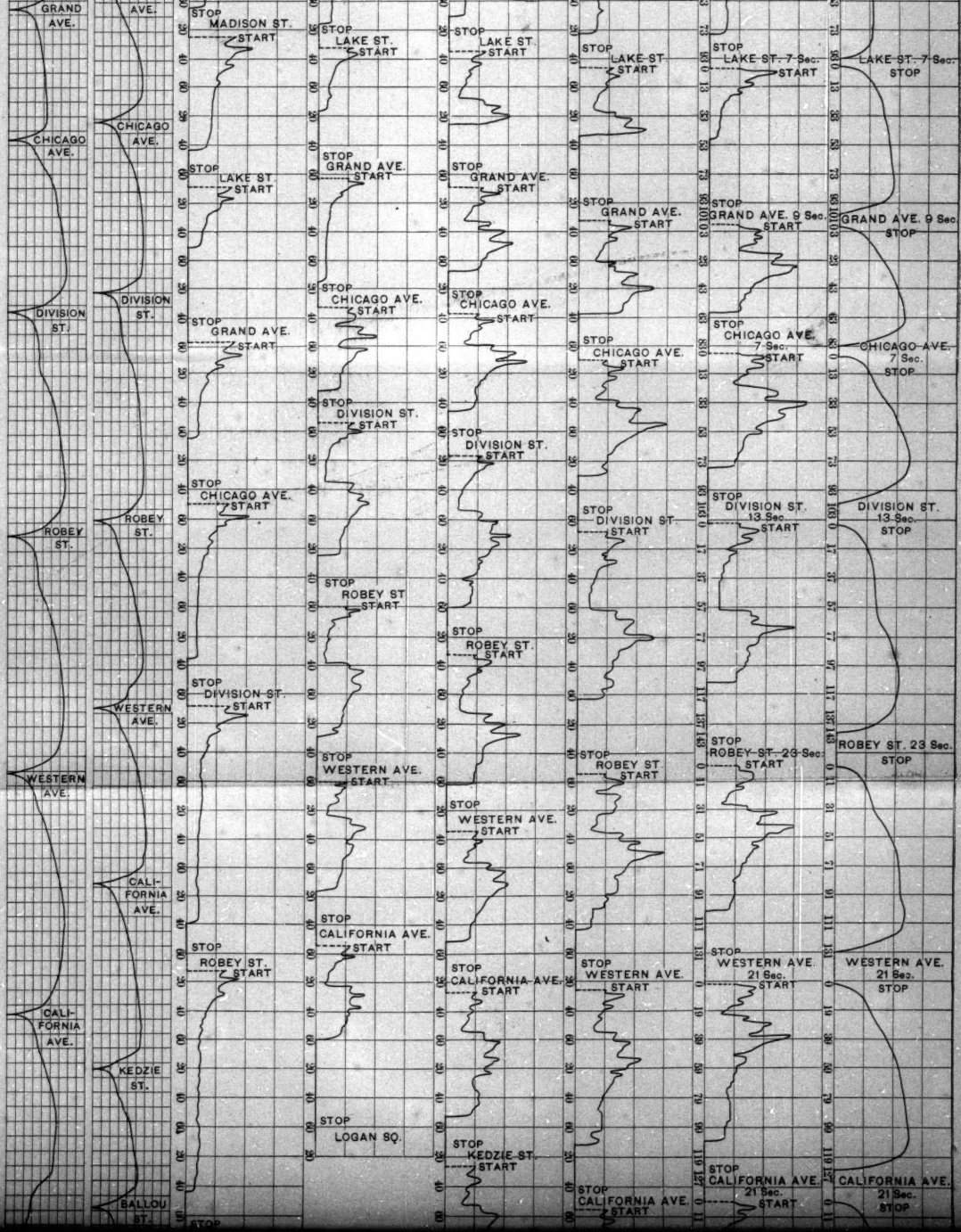
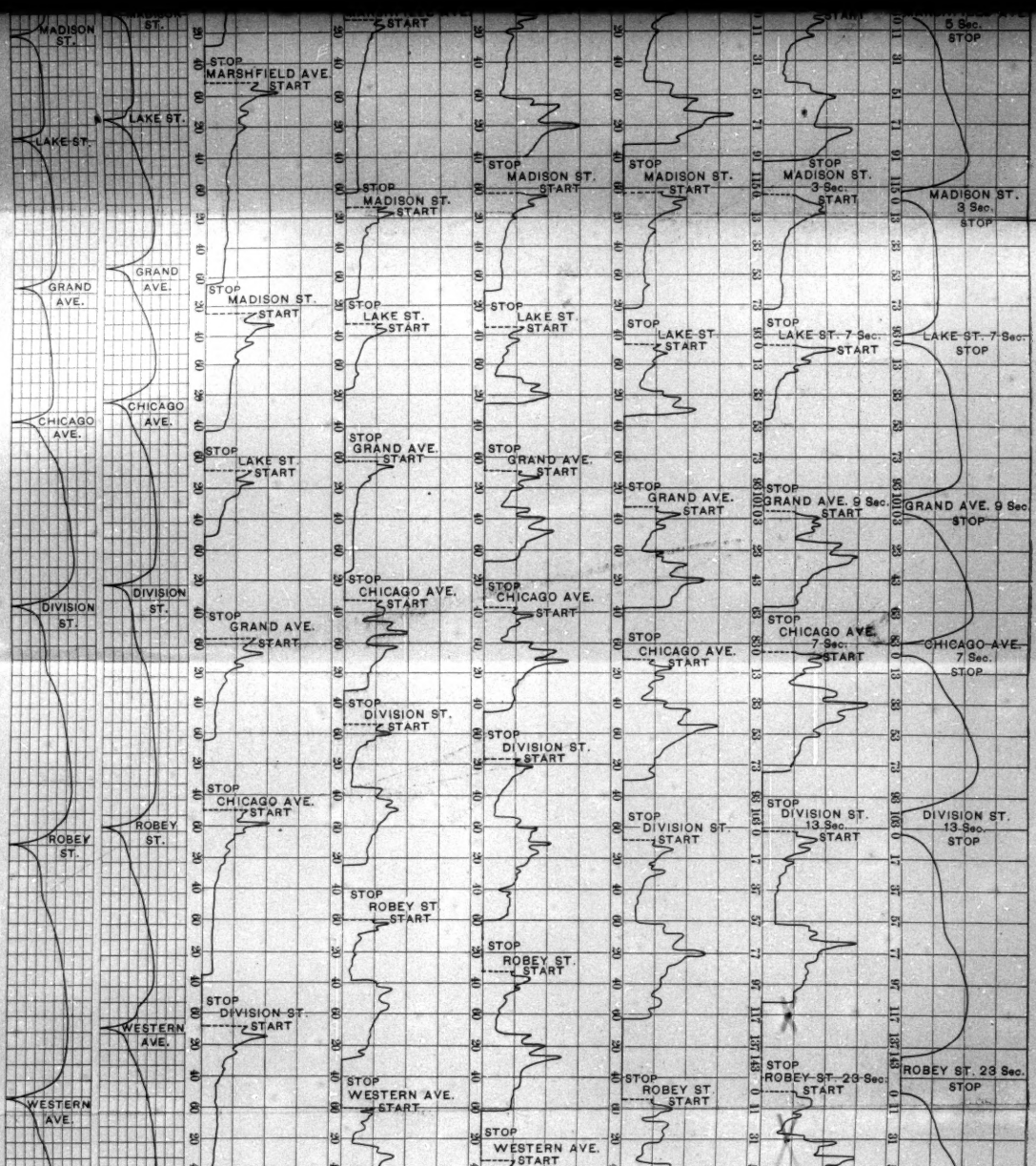


Fig. 19.
Fig. 18.
Fig. 17.
Fig. 16.
Fig. 15.
Fig. 14.
Fig. 18.
CURRENT
AMPERES
MILES PER HOUR
FRANKLIN ST.
CANAL ST.
HALSTED ST.
CENTER AVE.
LAFLIN ST.
MARSHFIELD AVE.
MADISON ST.
LAKE ST.
GRAND AVE.
MOTOR CAR NO. 722
PULLING 3 TRAILERS
MOTORS IN SERIES
PULLING 1 TRAILER
PULLING 2 TRAILERS
STOP
START
CANAL ST. 15 Sec.
HALSTED ST. 9 Sec.
CENTER AVE. 5 Sec.
LAFLIN ST. 7 Sec.
MARSHFIELD AVE. 5 Sec.
MADISON ST. 3 Sec.
SECONDS


GRAND AVE.
CHICAGO AVE.
DIVISION ST.
ROBEY ST.
WESTERN AVE.
CALI-FORNIA AVE.
KEDZIE ST.
BALLOU ST.
STOP MADISON ST. START
STOP LAKE ST. START
STOP GRAND AVE. START
STOP CHICAGO AVE. START
STOP DIVISION ST. START
STOP ROBEY ST START
STOP WESTERN AVE. START
STOP CALIFORNIA AVE. START
STOP LOGAN SQ.
STOP KEDZIE ST. START
STOP CALIFORNIA AVE. START
STOP WESTERN AVE. START
STOP ROBEY ST START
STOP DIVISION ST. START
STOP CHICAGO AVE. START
STOP GRAND AVE. START
STOP LAKE ST. START
STOP LAKE ST. 7 Sec. START
LAKE ST. 7 Sec. STOP
STOP GRAND AVE. 9 Sec. START
GRAND AVE. 9 Sec. STOP
STOP CHICAGO AVE. 7 Sec. START
CHICAGO AVE. 7 Sec. STOP
STOP DIVISION ST. 13 Sec. START
DIVISION ST. 13 Sec. STOP
STOP ROBEY ST. 23 Sec. START
ROBEY ST. 23 Sec. STOP
STOP WESTERN AVE. 21 Sec. START
WESTERN AVE. 21 Sec. STOP
STOP CALIFORNIA AVE. 21 Sec. START
CALIFORNIA AVE. 21 Sec. STOP


MADISON ST.
LAKE ST.
GRAND AVE.
CHICAGO AVE.
DIVISION ST.
ROBEY ST.
WESTERN AVE.
STOP
MARSHFIELD AVE.
START
STOP
MADISON ST.
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STOP
LAKE ST.
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GRAND AVE.
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CHICAGO AVE.
START
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DIVISION ST.
START
STOP
ROBEY ST.
START
STOP
WESTERN AVE.
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MADISON ST.
3 Sec.
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LAKE ST. 7 Sec.
START
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GRAND AVE. 9 Sec.
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CHICAGO AVE.
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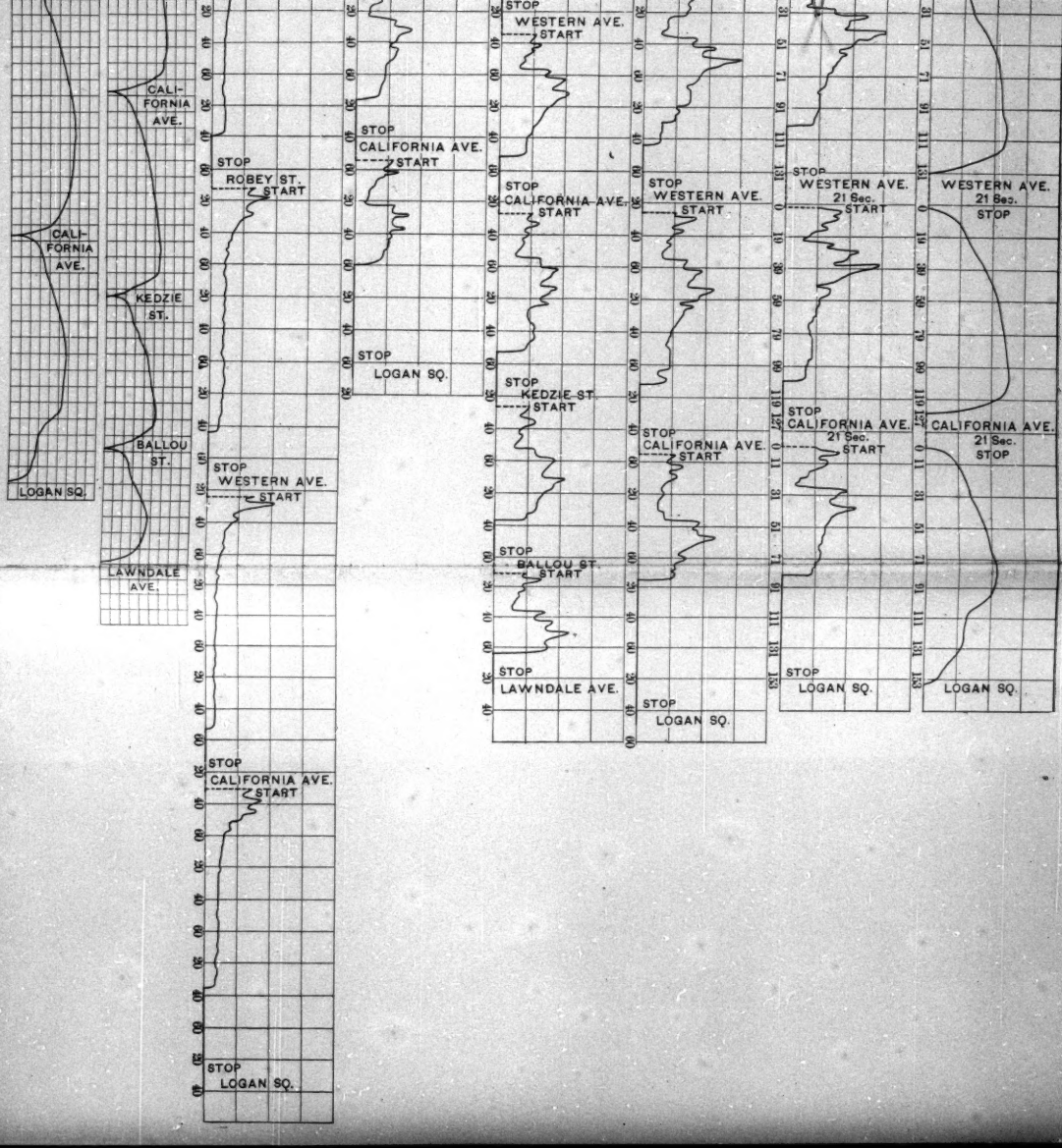
DIVISION ST.
13 Sec.
START
STOP
ROBEY ST. 23 Sec.
START
MADISON ST.
3 Sec.
STOP
LAKE ST. 7 Sec.
STOP
GRAND AVE. 9 Sec.
STOP
CHICAGO AVE.
7 Sec.
STOP
DIVISION ST.
13 Sec.
STOP
ROBEY ST. 23 Sec.
STOP


CALI-
FORNIA
AVE.
LOGAN SQ.
CALI-
FORNIA
AVE.
KEDZIE
ST.
BALLOU
ST.
LAWNDALE
AVE.
STOP
ROBEY ST.
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STOP
WESTERN AVE.
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LOGAN SQ.
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WESTERN AVE.
21 Sec.
START
STOP
CALIFORNIA AVE.
21 Sec.
START
STOP
LOGAN SQ.
WESTERN AVE.
21 Sec.
STOP
CALIFORNIA AVE.
21 Sec.
STOP
LOGAN SQ.

than half-a-cent per kilowatt-hour, and in the form of mechanical energy at the car axles, costing about one cent per kilowatt-hour, it is several per cent. cheaper than it can be generated by steam locomotives. Add to this the actual saving in energy from a more rapid acceleration and from reduced train weight and the total direct advantage for the electrical system is obtained as far as economy in power is concerned.

While any reduction in the cost of power (not only for fuel, but repairs, labor, water, oil and waste, etc.) is of great importance to railroads, the many other advantages of electricity, representing betterments of the service and greater earning capacity are the chief qualities which will determine its adoption in any case in place of steam locomotives. As a motive power electricity is simple, efficient and wonderfully flexible, and it is hardly wise to predict its limitations.

A paper to be presented at the 19th General Meeting of the American Institute of Electrical Engineers, Eliot, Me., July 27th, 1887.

[ADVANCE COPY, SUBJECT TO REVISION.]

HISTORICAL SKETCH OF THE FIRE ALARM TELEGRAPH.

BY ADAM BOSCH.

On June 3d, 1845, the *Boston Advertiser* published a communication by Dr. W. F. Channing, in which public attention was called to a new application of the telegraph, in these words: "There is a highly important application of the Electric-Magnetic Telegraph to which public attention has not as yet been directed. This is its use in our cities, to give an instantaneous, universal and definite alarm in case of fire. The peculiar properties of the telegraph—rapidity and precision of communication—are, in this instance, preeminently needed."

The writer then goes on to unfold his plan, substantially as follows: A central office was to be established in some public building, in which the necessary battery, together with a Morse register and an alarm bell, should be located; a double wire to proceed from thence over the housetops successively to every engine-house and fire bell in the city, and return again to complete its circuit to the place from whence it started. In every station thus established, a Morse register in connection with an alarm bell was to be placed, also a key, by the simple depression of which an appropriate signal would be instantly conveyed to every other station on the circuit.

He also suggested the modification of having five or six circuits, or even a circuit from every station, to the central office. By this method the operator would be able to communicate directly to all the stations, and, if so desired, every alarm of fire might be made to pass through the central office before being communicated to the different stations. From among the many

modifications to which his design is susceptible, Dr. Channing calls special attention to one, in these words: "There is, however, one which deserves to be specially mentioned. By a slight change of the arrangement at the alarm-bell stations, and increase of machinery, the hammers of the bells could all be disposed so as to strike mechanically on the communication of a galvanic impulse from the central office. The agent (operator) would therefore be enabled, by depressing a single key with his finger at certain intervals, to ring out an alarm defining the position of the fire simultaneously on every church bell in the city." This description clearly indicates the electro-mechanical bell striker, which had not yet been invented. In conclusion, Dr. Channing urges the municipal authorities to take his project into consideration; and, as the city had been behindhand in the matter of giving alarms of fire, the adoption of this system would place her in advance of other cities.

The next effort to apply the telegraph to fire alarm purposes was made in 1847, by F. O. J. Smith, who was at that time in charge of the Morse telegraph interest in the New England states. Mr. Smith consulted Moses G. Farmer, whom he considered one of the foremost electricians in the country, as to the possibility of striking a number of large bells simultaneously by means of electricity. Farmer agreed to produce an apparatus by means of which this could be done, and in a short time exhibited to Smith a model of his invention, the simple and beautiful piece of mechanism which afterward became well known as the falling ball electro-magnetic escapement. This was substituted for the mechanical escapement on a church-clock striking apparatus in common use at that time. Mr. Smith was highly pleased with the apparatus, and immediately submitted a plan for establishing a fire alarm telegraph to Josiah Quincy, Jr., Mayor of the City of Boston. This plan proposed connecting 15 engine-houses by telegraph, and equipping three large bells with electric-bell striking machines, the same to be operated simultaneously from some convenient point. Mayor Quincy, in his annual address, January 3d, 1848, recommended this subject to the consideration of the Board of Aldermen, which body acted on this recommendation to the extent of ordering two bell-striking machines for the city. They were made under the direction of Farmer, and, when completed, submitted to a public trial, which proved very satisfactory. After

this the city authorities took no further action in the matter, and Mr. Smith abandoned the subject.

Early in the year 1851, Dr. Channing, who had, in the six years since the first publication of his plans relating to the establishment of a fire alarm telegraph, spent much time and thought in his endeavor to shape public sentiment favorable to his project, sent an elaborate and well considered communication to the Mayor and Board of Aldermen of the City of Boston, commending his fire alarm system to their consideration, accompanying this communication with diagrams of the proposed signal and alarm circuits, a map showing the division of the city into six districts, a description of the apparatus required, an estimate of the probable cost, and also an offer to give a practical exhibition to demonstrate the feasibility of the system, if desired. The general outline of the system as proposed was as follows:

The city was to be divided into six fire districts. Three signal and three alarm circuits were to be constructed. To avoid possible interruptions of the circuits, all wires were to be run double. The ground was not to be used as any part of the circuit, for the reason that unauthorized persons might complete the circuit by establishing connection between the wires and the ground. The whole of the machinery of the signal stations was to consist of a signal key, locked in a small box.

The central office was to be located at the City Hall, and the apparatus to consist of a receiving magnet (relay) on every signal circuit, and a local circuit to operate a register and alarm bell. For an apparatus to transmit alarms to the large bells, the employment of an instrument moved by clockwork, then well known in connection with the Morse telegraph, was suggested. This consisted of a cylinder made of wood, having a metal core, over which a number of keys fashioned like piano keys were arranged, and under each key, strips of metal in groups, were fastened to the cylinder and connected with the core. When this cylinder was set in motion and one of the keys depressed, a spring would bear on the cylinder, and, if properly connected, a signal was given corresponding to the number and position of the metallic strips under this particular key. It was in connection with preparations for the proposed exhibition previously mentioned, that Dr. Channing made a search for the two models of bell-striking machines made in 1848 for the city. He found them stowed away in a lumber room, and covered with dust.

He had himself devised an electric escapement for bell-striking machines, but he quickly recognized the great superiority of the one invented by Farmer, and therefore decided to use the models in his public demonstration. Desiring to obtain the inventor's assistance at this exhibition, he sought an interview with Farmer, who readily consented. At this meeting they agreed to join their interests and co-operate in all matters relating to the establishment of a fire alarm telegraph. An exhibition was soon given before the Mayor and Board of Aldermen, at which Farmer assisted. It proved highly successful, and resulted in an appropriation of $10,000 by the city government for the purpose of carrying out the proposed plans.

At the urgent request of Dr. Channing, Farmer was appointed Superintendent of Construction. He entered upon his duties at once and with characteristic energy. The task before him was not an easy one. "Something new under the sun" was about to be established. For months nearly all the work was experimental; apparatus was constructed and discarded as defects manifested, or improvements suggested themselves.

In the construction of the signal boxes the first departure from the original plan was made by adding a wheel and crank to operate the key. This wheel had certain definite projections upon it, their width and position varying with the signal to be conveyed, the wide projections being for dashes, the other for dots. On turning the crank each projection on the wheel would in its turn open the key, and keep it open for a longer or shorter period of time according to the width of the projection. The handle of the crank was weighted for the purpose of maintaining the wheel in its normal position where none of its projections were in contact with the key.

It was soon discovered that considerable skill was required to operate this device with any degree of regularity; the motion of the crank in unskilled hands was so irregular that the signals could not be distinguished as printed by the register. This was therefore discarded, and other apparatus constructed with the same break-wheel, but the crank was so arranged in connection with two gear wheels that two revolutions of the crank were necessary to produce one revolution of the break-wheel.

Considerable trouble was also experienced in the point of contact of the signal keys. This was remedied by substituting a sliding contact. In the original plan the signal box was designed simply

to transmit the number of the district in which it was located. The improved apparatus also gave the station number; the district number by dots, and the station number by dashes and dots; this added greatly to its value as a means of indicating the exact locality of a fire.

But the most radical departure from the plan was made by placing the signal boxes on the outside instead of the inside of buildings as originally intended; this change necessitated better protection for the apparatus. This was effected by placing the iron case which contained the mechanism into a strong iron box, in form similar to the one in general use for that purpose at the present time.

If the difficulties encountered in the construction of the signal box apparatus were great, those met with in the construction of the bell-striking machines were gigantic. Farmer's original models were made to strike bells weighing from 75 to 150 lbs., and now 19 machines were to be built to strike bells weighing from 300 to 3700 pounds.

It was necessary that all the bells whether large or small should be struck successive blows in the same short period of time, and, to satisfy the public, that they should be struck with a force no less than that by which they were formerly struck by means of rope and tolling hammer. To accomplish this, weights of from 800 to 2000 pounds according to the size of the bell to be struck were found to be necessary. Every point in connection with these machines had to be determined experimentally. It was a problem without any known factors. Machines were built, tried and discarded. For the largest size bells three machines were built before one was found to answer the purpose.

Locality had to be considered. In some of the belfries the space for the machines was ample, in others it required various modifications of the apparatus in order for it to be properly placed. What added greatly to the perplexity of the situation was the fact that all the experiments had to be made in public. To test the machinery it was necessary to strike the bells, and, it is therefore not to be wondered at, that complaints about the incessant clanging of the bells were heard all over the city. The citizens were far from being unanimous in favor of the experiment. The man who knows it won't work, as well as the man who knows that even if it does work it won't be as good as the old method; both resided in Boston at that time as they reside

everywhere, where important improvements are about to be made. Dr. Channing who was a charming writer, wrote many articles for the daily papers in order to create a stronger public sentiment in favor of the experiment.

As in the original plan the apparatus furnished for the central office consisted of a cylinder transmitter or key-board as it was called, very much improved; the keys were so arranged that simply depressing one of them would liberate the clockwork and start the cylinder, and upon releasing the pressure it would come to a stop in its normal position. In order to economize battery power, three metal springs were placed on the underside of the keys. Each spring was connected with one of the three alarm circuits and so arranged that as the cylinder revolved, each metal strip on its surface would make connection with each spring successively, thus allowing the same battery to be thrown on each one of the three circuits in quick succession.

For the Morse register to be used in connection with the alarm circuits to indicate the number of blows struck on the bells, an indicator was devised consisting of three revolving cylinders on which the numbers were exhibited in large plain figures.

On another instrument not mentioned in the original plan but very useful and important was an automatic circuit-testing clock which tested the circuits once every hour.

In the spring of 1852 the system was so far completed that it was deemed sufficiently reliable to submit it to public use. Nearly a year had passed since the work was begun. The time required as well as the cost, far exceeded the original estimates. The $10,000 appropriated at the beginning was spent long before the work was completed, and a further appropriation amounting to nearly $6,000 were found to be necessary. This was caused partly by the extraordinary difficulties encountered, and partly by the extension and improvement of the system beyond the requirements of the original plan. Thus instead of 26 signal stations, 39 were established.

April 28th, 1852, was decided upon as the day on which the new method of giving alarms of fire should go into effect. That there was considerable misgiving concerning the reliability of the new system, and which, as the result showed, was not altogether groundless, the following extract from the printed directions issued before the telegraph went into use will abundantly show:

"Before giving an alarm be sure that a fire has occurred within "your district; being reasonably certain of that, turn the crank "within the box, say ten times, not too fast, and wait. If the "signal is perfect, you now have registered at the central office "the number of your district, as well as the number of your box. "If the alarm is heard at the central office, the operator there "will indicate the fact to you as soon as you have ceased, by "striking the number of your district with the small magnet in "your box, twice at least. Should you not hear this, turn the "crank again, more slowly. Should you not then hear the "response, go to another box, and if equally unsuccessful there, "carry the alarm yourself to the central office."

That the latter injunction was not unnecessary is evinced by the entry in the Journal of the Central Office, on April 29th, the day after the telegraph was given over to public use, thus, "First Alarm, 8.25 P. M. from Station 7, District I, J. H. Goodale turns the crank like lightning could not read; brought alarm to office." In this case the register failed on account of the great speed with which the signal was sent. During the striking of this alarm on the bells, four machines were disabled. For many months after the system went into operation, serious defects were continually developing, and a time of great anxiety for its projectors ensued. Farmer and his assistants, in ceaseless activity, spent day and night modifying, improving and adjusting apparatus. The alarm bells were a source of the greatest trouble and anxiety; their failure to strike correctly encouraged the opposition to the system to renewed effort in which, strange to say, the firemen were most prominent. But gradually, by unremitting exertion difficulty after difficulty was overcome, and by the end of the year a reasonable amount of confidence was felt in the reliability of their performance. Another cause of anxiety, especially to the operators at the central office was the irregular manner in which the crank was often turned, giving an alarm from the signal boxes; some persons laboring under intense excitement would whirl it around with a speed that fairly defied the register to print the signal; others, mindful of the instructions to turn slowly, would turn the crank with such exaggerated deliberation, that it required a long investigation on part of the operator which was not always successful, to distinguish dots from the dashes. On January 1st, 1852, in view of the early completion of the work, and in order to retain his services for the first few months of its practical

operation, the Board of Aldermen had elected Farmer superintendent of the new system for a term of six months. It was generally conceded that no one else could make it a practical success. The friends of Farmer who urged him to accept the position, deemed it of the utmost importance that the experiment should be made a success from the beginning, as a failure at that time in Boston would be fatal to its introduction into other cities. Farmer accepted the position, but instead of six months, three years passed before he considered the system in such a condition that he might safely place its management into other hands.

The first city after Boston, to adopt the fire alarm telegraph was Philadelphia, where it was introduced in 1855.

In 1855, Dr. Channing, who had done much to bring the subject of the fire alarm telegraph before the public and city authorities, delivered a very interesting lecture before the Smithsonian Institution. It was through this lecture that the attention of J. N. Gamewell was first directed to the fire alarm telegraph. On the occasion of a visit, Professor Henry called his attention to the lecture and presented him with a copy. Immediately after its perusal he started for Boston and acquired the rights for the southern and western states.

The fundamental patent covering the invention of the fire alarm telegraph, as exemplified by the Boston system, was granted to Channing and Farmer, May 19th, 1857. Another patent was issued to them in March 8th, 1859 for a repeater.

The following patents relating to fire alarm telegraph apparatus were granted to Farmer alone.

May 4th, 1852; Electro-Magnetic bell striking apparatus.

Jan. 11th, 1859, for an improved signal box, in which the magnets were shunted by the closing of the outside box door, a practice that has been followed up to the present day.

February 22nd, 1859 for an automatic system in which the central office is dispensed with, and the signal boxes and alarm bells are all placed on one circuit, and where consequently, when an alarm of fire is given, all the bells will strike instantly and simultaneously, without the aid of an operator. This was called the village system, from its adaptability to small places, where the expense of a central office would be prohibitory.

Two other patents were granted to Farmer in 1859. One was for an "electric-magnetic apparatus for setting water motors in motion." This was applied, for a short time, to operate some of

the bell-striking machines of the Boston system in place of weights. The other patent was for "Mechanism for operating signal whistles by electro-magnetism."

A very important improvement was made in 1856 by Chas. T. Chester, to whom a patent was granted for an "automatic electrical circuit breaker." In this apparatus the break-wheel was moved automatically by means of clockwork actuated by a spring. Although this particular apparatus never came into public use, it is practically the first automatic signal box of which we have any knowledge.

After three years of agitation and hard work, Gamewell and Company met with their first success in the city of St. Louis, where they installed a plant in 1858. St. Louis was, therefore, the third city to adopt the fire alarm telegraph.

In 1859 the same firm obtained, by purchase, complete control of all patents relating to the fire alarm telegraph granted to Channing and Farmer, or to Farmer alone. Mr. Gamewell early recognized the fact that a fire alarm telegraph having one of its most vital parts, the signal box, constantly exposed to the elements, to the heat of the summer and to the cold of winter, to rain and to dust, unused until an emergency arises, and where a failure of the apparatus to properly operate in that emergency might result in the destruction of property to the value of millions and even in the sacrifice of human life, should have the best apparatus that ingenuity could design and the highest skill execute. With this object in view, he soon gathered around himself men of inventive genius and great mechanical skill, three of whom especially distinguished themselves by inventions of the greatest merit. These are Edwin Rogers, James M. Gardiner and Moses G. Crane, three names inseparably connected with the development of the fire alarm telegraph. One other name should not be forgotten, that of John Polsey, to whose superior mechanical skill much of the early success of the fire alarm telegraph is due.

The first fire alarm system, equipped with automatic signal boxes was introduced into the City of Mobile in 1866. This was an automatic system, but, unlike Farmer's village system, in which all the apparatus is placed on one circuit, four circuits were provided. This had never been attempted before, and to make it possible in this case, a new apparatus had to be invented, by means of which a signal from any one circuit would be auto-

matically transmitted to every other circuit, and which would mechanically close every other circuit, should any one circuit remain open. This was accomplished by Edwin Rogers, to whom a patent for the first automatic repeater for fire alarm purposes was issued in 1870.

The original crank signal boxes remained in service in Boston until 1866, in which year automatic boxes were substituted in their place. The following year, Joseph B. Stearns, the immediate successor of Farmer in the superintendency of the Boston fire alarm telegraph, received a patent for an apparatus operated by "reverse currents," which permitted the simultaneous use of the same wire for receiving a signal from a box and transmitting it to the alarm bells. Several years prior to the introduction of automatic signal boxes, Stearns abandoned the method of striking the district numbers on the bells, and new boxes were designed to strike the box numbers only. While, with the adoption of the automatic signal box, the speed with which a fire alarm box was operated, no longer depended on the temperament or mental condition of the person giving the signal, a proof was soon furnished that, in a matter of this kind, as little as possible should be left to the intelligence of the public. Incorrect signals were often received from these boxes, for the occurrence of which no cause could be assigned. It was usually the first "round" that was found to be wrong. This remained a puzzle until the cause was discovered, which was this—that the person giving the alarm, disregarding the instructions to "pull the hook down once and let go," would, after the first pull, by way of emphasis, give the hook another pull or two. This would momentarily suspend the movement of the break-wheel, and if it occurred between two successive breaks, a long pause would ensue, and the signal would be either unintelligible or a number entirely different from the box number would be transmitted. For inventions to remedy this difficulty, two patents were issued in 1869 for "non-interference pulls," one to Stephen and Chas. T. Chester, and the other to Edwin Rogers and Moses G. Crane. In the former invention, the arrangement was such that, after the box was in operation, the hook could not again engage the mechanism until the full number of "rounds" were completed; in the latter, the mechanism could be engaged after each full round.

There was however another interference of a very serious na-

ture which often resulted in trouble and delay; this was the interference caused by pulling a box while an alarm from another box was in process of transmission. It is not a very unusual occurrence to have two or three boxes pulled for the same fire, and if these boxes happened to be on the same circuit, and the second was pulled before a full round of the first box was completed, a mixed alarm was the result. In such cases it was usually, but not always possible to obtain the correct signal from the last round of the second box.

The first patent for a non-interference box was issued to J. N. Gamewell in 1871. This is a normally wound box (all other automatic boxes were either actuated by weight, or if by spring were pull wound) with trigger pull, and a so-called skeleton break-wheel, that is, a wheel which in its revolution will keep the circuit open for the greatest length of time consistent with the proper transmission of the signal. It also contains an electro-magnet, and an armature which when it is in a position away from the magnet shunts the break-wheel. If the box is pulled while the armature is in its normal position against the magnet it is held there by a simple contrivance until the signal is completed. If a box is pulled while another one is in operation, the same contrivance will hold the armature in a position to shunt the break-wheel of the second box during the time of its operation, and therefore no interference can take place. The only chance of an interference lies in the possibility that the hook of the second box should be pulled the instant the circuit is closed, and the armature held close to the magnet, but, as owing to the construction of the skeleton break-wheel these periods of contact are exceedingly brief the chances of an interference are very remote.

In 1880 J. M. Gardiner received a patent for a non-interference signal box which on account of its great simplicity and mechanical perfection has maintained its great popularity to the present day. In this box non-interference is not effected by shunting the break-wheel, but by a very simple method the box pulled while another box is transmitting its signal is rendered mechanically inoperative. This is accomplished in the following manner. A small electro magnet in connection with the clock-work has an armature with a wide range of movement, so that when fully withdrawn by a retractile spring it is beyond the attractive force of its magnet. An extension on this armature carries a

small movable disk. This disk when the armature is in its normal position drawn to the magnet, takes a position between the detent of the movement and the starting lever. If, while it is in this position the box is pulled, the starting lever raises the disk which in turn raises the detent, and allows the clockwork to start. A stationary pin on the outside door restores the armature and holds it close to the magnet whether the circuit is open or closed. The skeleton break-wheel is also an essential feature of this box, and consequently during the entire transmission of a signal the circuit is never closed longer than a small fraction of a second at one time. If while a signal is being transmitted an attempt is made to pull another box the following will take place. Before the door of the box is opened an inch, the restoring pin will be withdrawn and the armature becomes free to recede, and before the door can be entirely opened and the hook pulled it will be withdrawn, together with the disk but without the disk interposed between the starting lever and detent the movement cannot be started.

One of the most effective remedies proposed for preventing the interference of signals, is the system of interlaced circuits for which J. N. Gamewell received a patent in 1875. In carrying out this method the circuits are run in such a way that no two adjacent boxes are on the same circuit. This is most easy of accomplishment in cities occupying a long but narrow territory. In cities less favorably situated the great amount of wire required to fully carry out this principle has been a bar to its general adoption. An additional advantage derived from interlaced circuits is this, that in case of an open circuit no two adjacent boxes will be out of service at the same time.

If two signal boxes of the non-interference type are pulled about the same time, the one that has precedence by as much as the fraction of a second will transmit its signal, while the other will be inoperative. To prevent the loss of this signal, John J. Ruddick invented a signal box in which this is accomplished in a very ingenious manner. With these boxes in circuit any number may be pulled at the same time, and all will respond successively. While this would be an advantage in the extremely rare cases where two boxes on the same circuit are pulled at the same time for two different fires, it would be a positive disadvantage in all other cases where a number of boxes are pulled for the same fire, to have the circuit occupied trans-

mitting unnecessary signals, should the firemen upon their arrival at the fire find a special call, or a second alarm necessary.

A problem which has not received an altogether satisfactory solution, is how to make the signal boxes readily accessible to any one in case of fire, and in a way that will not at the same time render it easy to give false alarms.

For this purpose a keyless door on fire alarm boxes has been somewhat extensively used in the larger cities; these doors are simply closed by a latch and opened by a handle. On turning the handle to open the box, a concealed gong starts to ring loudly and thus attracts attention; this device answers very well for a densely populated section of a city, but in the sparsely populated portions, its benefit is not so apparent. Many cases are also on record where persons who opened such doors with the intention of sending in an alarm, failed to pull the hook, being under the impression that the striking of the gong was an indication that the signal was being transmitted.

Other methods, such as placing the key in a small box with a glass front easily broken, and located conveniently to the signal box, or over the key-hole with the key permanently inserted therein, have been tried with more or less success.

A traplock on the doors of signal boxes with keys numbered and the holders name registered, and where consequently a key in the hands of a malicious person can be used but once, has been found very effective in reducing the frequency of false alarms.

In one of the most original plans proposed, the boxes are placed inside of booths with mechanism so devised, that upon pulling the hook, the door of the booth will close and hold the person giving the alarm a prisoner until released by the proper authorities.

In another invention, for which a patent was issued, the booth was dispensed with, but instead, the box was provided with hidden mechanism which when released by pulling the hook, would firmly clasp and hold the wrist of the person sending the alarm. For reasons obvious to everyone but the inventors, neither one of these inventions ever found its way into public use.

A not inconsiderable share of the unreliability of the fire alarm telegraph in its earliest stages must be ascribed to the source which supplied the electrical energy. The Grove cell then used was not well adapted for service on a fire alarm tele-

graph, where uniformity of current strength is such an essential requirement. The Daniel cell, by which it was succeeded, was much more satisfactory, and was generally employed up to the year 1871, when the Callaud or gravity cell was introduced. The superior merits of this cell were soon recognized, and in a very short time every fire alarm telegraph was equipped with it. For over twenty years it was the only cell used for this service. Within the last two or three years, however, it has been superceded in a number of places by the storage battery, with very satisfactory results.

In one instance the gravity cell has been replaced by the dynamo. Superintendent Brown Flanders, of the Boston Fire Alarm Telegraph, about five years ago, applied the dynamo current to a single circuit. Its application was gradually extended, and at the present time the entire plant is operated by dynamos.

The automatic repeater invented by Edwin Rogers was gradually improved by him, as well as by the labors of J. N. Gamewell and Moses G. Crane, until it has become an apparatus of almost absolute reliability. While a signal from any one circuit attached to this repeater is being transmitted, all the other circuits are mechanically locked out, and thus confusion is prevented should a box on any other circuit be pulled at about the same time. It is also provided with a device whereby the armature of the operating electro-magnet is mechanically restored after each break of the circuit, and little more, therefore, is required of electricity than that it should hold the armature in position; consequently it will perform its functions successfully under greatly varying conditions of current strength, a very important consideration in an automatic system, where constant attention cannot be given to the care of the battery or the adjustment of the apparatus.

The electro-mechanical gongs have also been greatly improved, and nearly all are provided with armature-restoring devices, and for the use of fire departments, where the men are not permanently in their houses, they are provided with indicators which expose the number of the signal in large figures.

The general plan of a modern central office fire alarm system still resembles that outlined by Dr. Channing, fifty-two years ago; but, in the instruments and apparatus used, most wonderful improvements have been made.

In the modern central office, the Morse register has been

replaced by the multiple pen register, which has the merit of greater compactness, and may accommodate both the signal and alarm circuits, with this advantage, that, as the records are printed in parallel lines on the same paper, their relative positions will indicate, to a second, the time elapsed between the reception of the signal from the box and its transmission to the engine-houses; it thus also incidentally serves as a record of the degree of promptness with which the operator has attended to his duties.

The old keyboard, at an early period, gave way to a dial transmitter still in use in several cities. In this apparatus there is a separate dial and index for every digit in the number to be transmitted. On receiving a signal from a box, the operator moves the indexes to the respective figures and starts the clockwork into action.

Another method, and one still in use in New York city, is to have a duplicate break-wheel for every signal-box number in the system. The operator, on receiving a signal of fire, selects the corresponding wheel and inserts it on the wheel shaft of the transmitter.

In one of the most improved modern transmitters the dials are all placed on the same shaft, the first dial on the shaft is stationary, and has engraved upon it the figures from one to nine, in as many series as there are movable dials, the other dials simply have apertures which in operation are turned so as to expose the numbers to be transmitted. This apparatus is manipulated with great rapidity, and as only the numbers to which the apparatus is set are exposed to view, the liability to error on the part of the operator is reduced to a minimum.

The testing clock of the original Boston central office has been succeeded by an automatic testing apparatus of excellent design and beautiful workmanship, which indicates and makes a record of the condition of the circuits at stated periods of time.

The best practice demands that there should be two separate circuits to communicate alarms from the central office to the engine houses so that in case of trouble on one circuit, the alarm may be received on the other.

In central offices equipped with new apparatus within the last few years every safeguard is provided to prevent mistakes in the transmission of alarms. With the first blow on the gong from a box signal, a cylindrical indicator revolves and exposes the num-

ber of the circuit from which the signal is being received, as well as the number of every box on that circuit. The operator may therefore while counting the signal, set the transmitter, and with one glance at the printed record of the register, and another at the circuit indicator, verify its correctness and have the alarm in process of transmission within five seconds after the completion of the first round from the box.

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[ADVANCE COPY—SUBJECT TO REVISION.]

THE COST OF STEAM POWER.

BY HORATIO A. FOSTER.

In this age of electricity, when so much is being done in the way of developing its applications, and especially in its application to the transmission and distribution of power, perhaps no one item causes so much controversy as the cost of steam and other familiar forms of power. It seems to have been taken for granted for years that anyone and everyone knows the cost of developing power by steam, and in almost all cases when a person stating such costs is pinned down to facts, it has been found that he is either guessing, or quoting those he supposes are authorities. It is to be presumed that statements of actual tests for cost might have been published, but the writer has in a somewhat extended search run across but one such statement that might be considered reliable and that was a test for something under 100 days, and that practically confined to the warm season of the year and not therefore of the greatest value.

Other estimates have been made from extended experience and carefully revised theory, and in fact little can be added to tables published during the past few years by some of our most eminent and best qualified engineers, in the way of carefully prepared estimates of what should perhaps be called the average cost of producing steam power under various conditions as to amount of power and the type of machinery employed.

It must be said, though, that almost all these estimates have been made for powers of large size and where little variation of load takes place, and, while such estimates are of great value for use in discussion of the subjects, the writer has found them somewhat unsafe to use unless their results are applied in con-

nection with extended experience, for, while the results considered as averages are probably correct for ordinary conditions, they cannot of course be expected to include extraordinary conditions, and the results of this investigation seem to show that individual cases vary so much that it is not fair, and may be misleading to state average costs.

It seems a pity that the cost of power is most often quoted for one horse-power for one year, and so freely assumed that there is an average cost of power on which one can base estimates in the cost of manufacture; for the writer will endeavor to show, as this paper progresses, as others have done, first, that any general statement of the cost of power per horse-power per annum is incorrect, for the reason that such a statement does not ordinarily take into account the number of hours run per diem, or the number of days per year, and even in that class of plants supposed to run, say 308 days per annum, it is seldom one can be found that runs a full year, and no two run the same length of time; and second, that no such statement of an average cost of power is of any value whatever, unless it be for plants employed in similar work, and under exactly similar conditions, and even then the amount of power developed is such a factor for varying the unit cost that it is in the opinion of the writer quite fair to say that there is no average unit cost for steam power, that is safe for general application, and it is thought that a somewhat careful study of the tables and computations accompanying this paper will help to a clearer understanding of the reasons therefor.

Although in the great majority of instances office accounts are so kept as to give no real basis upon which to compute the cost of power, and in most off-hand estimates, the rated capacity and not the average power developed has been used as a divisor, there can be no doubt that in some of the older industries, say in the great flour mills and the large eastern cotton factories, where prices of manufactured goods have been tending downwardly for so many years, and very close accounts of unit cost have necessarily been kept, and, as in all other departments the power has been very carefully looked after, that in such cases it is very likely that careful comparisons will show the cost of power to be more or less uniform when used under similar conditions, but reference to the tables will show this to be more widely at variance than is commonly thought.

It will be the endeavor of the writer to show by tabulated data as far as possible, the condition of the plants tested, without going any more into detail than seems necessary for a clear understanding.

In order that the value of the results may be determined, it is necessary to give some description of the methods pursued in obtaining them, and, as they were as far as possible the same throughout, a general description will do for all except the special cases.

In order that the greatest value might be obtained, it has always been the opinion of the writer that no results for a period short of twelve consecutive months should be used, and in all but one case which was for eleven months, a year has been taken as the smallest unit of time.

In a general way, the unit of time having been settled, where possible a unit of output was selected, after a careful and somewhat extended study of the special business in all its conditions, on which averages could be constructed and which could be turned into horse-power after determining its rate.

Indicator tests were always made both for determining the rates of power and the ratio of power to the unit of output: for instance, in a flour mill it is only necessary to apply indicators to the engine cylinder for a certain period of time, not less than 24 hours, and to count the actual output in barrels, to determine a fairly accurate ratio of horse-power per barrel of production, after which it is a simple matter to determine the average for a year from a total production and the actual time during which the mill was running and the output recorded; or in an arc lighting station, if an indicator test is made of the engine for the entire time per day, during which lamps are burned, and the number of lamps running during the same period be recorded, then also it is easy to determine the ratio of power to lamps, whence by computation from the records kept of the number of lamps burning and the time in hours during which they were lighted for a year, the lights can be reduced to horse-power, and if accurate and well classified records of expenditure are kept, the annual and hourly cost of power is determinable to a close degree of accuracy. Of course, wide variations in the amount of power used will often change the ratio, but care has been taken in these tests, not to base them on periods of changing power consumption, and it is therefore

thought that the results are within the ordinary limits of accuracy.

For the sake of uniformity, as well as to reduce the items of account to as small a number as was considered consistent with clear understanding, a list of cost accounts was determined on, that in most ways agrees with work previously done in this line, and which it was thought could be most easily met by the most ordinary bookkeeping.

The list is as follows:

Operating Expenses.

Fuel.
Wages.
Supplies.
Repairs.
Water.
Incidentals, including lighting and removal of ashes.

Fixed Charges.

Interest on cost of plant.
Depreciation on value of plant.
Insurance.
Taxes.

In considering the value to be given to each item, many things had to be discussed in order that proper separation of expenditure due to items other than for power could be made, as for instance the item of fuel; in many cases buildings have had to be heated, either by exhaust or live steam; steam has been used for hot tables, as in the case of newspaper offices, and for dry rooms for lumber etc. as is the case of a furniture factory. In all such cases the study of the plant, consultation with the engineer in charge and the management, coupled with the experience of the writer has ensured the determination of an amount satisfactory to all concerned as being the nearest correct obtainable under the ordinary conditions of practice.

In the item coming under the head of fixed charges, a somewhat different treatment obtained, as so little attention is given these items by the ordinary business management that in most instances not only the value of the plant, but the items going to make up the fixed charges had to be determined by the writer from his experience, together with such information as could be gotten from the people in charge. While insurance and taxes were of course determinable from the books, interest was rated in almost all cases at 5 per cent., and depreciation at rates varying

from 2½ to 10 per cent. for building, and 5 to 15 per cent. on steam plant, all according to type of material in use, its condition, the manner in which it was handled, etc. In but few cases were either of these items considered in the estimates of cost by the owners. It must be remembered in this connection, that fixed charges go on all the time, 24 hours per day for 365 days, and that the unit cost is the same if computed by the year, but does not have the same relative value when computed by the number of hours the power was actually in use. In passing, it may be well to say that the number of firms in good business standing that are entirely at sea regarding the actual cost or present value of power plant is to say the least astonishing.

One item taken into consideration in all the tests, and one seldom considered at all in the ordinary statements of the cost of power, is the value of the building or part of the building devoted to the use of the power plant. In some few cases buildings were set apart for this purpose, and where the value was known it was of course easy to fill out the item; but in cases where the power plant was in the same building with the other portions of the plant, it became necessary to set off the value from the rest, and this was most often done by determining the renting value of the room used, which can usually be done with small chance of error, and then to capitalize the rent as the value of that part of the building devoted to power purposes.

In one item used in these tests, the writer apparently differs from most other estimators of the cost of power, and that is in the use of the indicated horse-power rather than brake horse-power for the divisor, and his reasons for using it are as follows: viz:—Indicated horse-power can nearly always be determined to a degree of accuracy only limited by the usual errors of instruments and their users, generally conceded to be small; while brake tests can seldom be made in practice, and the net power is therefore most often determined by assuming a certain percentage of engine and shafting efficiency which under general conditions is quite incapable of proof, and the errors of which must be added to those of the indicator test. The writer therefore prefers to eliminate this chance for error, and should any one desire to change the figures here displayed to brake horse-power, it is only necessary to make the single computation due to any engine efficiency that he may wish to assume.

Referring now to plants tested, those on which reports were

made were not selected in order to show the very considerable variation in results that are given, but for availability and for variety of types and of business.

The plants on which tests were made for unit cost of power were:

Two Electric Lighting Stations.
One Grain Elevator.
Three Water Works Pumping Stations.
Two Flouring Mills.
Six Cotton Mills.
Four Newspaper and Printing Offices.
One Department Store.
One Furniture Manufactory.
One Bakery.
One Glazed and Fancy Paper Manufacturing Company.

The criticism may be offered that not enough plants were tested in any one business to determine an average cost of power in that business, and a careful inspection of the following tables will show that comparisons of cost of power between unlike types of business are of little value, and if still further comparisons be made, it will be found that conditions vary so much in the same type of business as to show that any statement of an average cost of power even there is quite misleading and that therefore tests of even a single plant of any of the different classes of business is of value only so far as it determines the cost for that plant alone, and demonstrates the fact of which the writer has become thoroughly convinced, that each plant must be tested as if it were the only one of the type in existence.

Coming now to tables, table I for easy reference, gives the number of the plant, the number and type of boilers, with all their dimensions, and the nature and cost of fuel used.

Table II is a continuation of table I, stating the number and type of engines used with all cylinder dimensions and rated power: the total plant value with the value per rated horse-power; the number of men employed with their average wages, and remarks on the use of steam for purposes other than for power, when taken from the boilers supplying the engines.

The above tables, perhaps, need little explanation, as all items are placed in columns so that results shown in other tables can easily be traced back and possible reasons for the conditions be shown in the plant equipment or the way it may be handled.

TABLE I. POWER PLANT EQUIPMENT. BOILERS AND FUEL.

No. of Plant.	BOILERS.									FUEL.	
	No.	Type.	No. shells each.	Diameter shells in inches.	Length of shell in feet.	No. tubes.	Diameter tubes in inches.	Square feet grate surface.	Steam pressure carried pounds.	Kind Used.	Average cost per 2,000 lbs.
1	2	Vertical, fire tube	1	96	14	270	2½	54	125	Soft Slack	$2.01
2	2	Horizontal return tube	1	60	16	48	4	20	80	Soft run of mine and slack	1 82
3	1	Horizontal return tube	1	72	16	86	4	36	80	Pea and Nut Anthracite	2.25
	2	Horizontal return tube	1	54	12	52	3	18	80		
4	1	Horizontal return tube	1	48	12	58	3	..	90	Natural Gas	Per month
	1	Horizontal return tube	1	60	14	78	3	..	..		
5	1	Horizontal return tube	1	60	13	64	3½	22½	60	Soft Nut and hard Screenings	1.94
6	2	Horizontal return tube	1	60	14	58	3½	25	75	Soft Coal. Yough	2.00
	1	Horizontal return tube	1	48	12	54	3	16	80		
7	4	Water tube. "B. & W."	2	42	18	126	4	119	140	Hard and Soft Slack	1.45
	2	Water tube. "Geary."	1	44	21⅝	139	4	42	140		
	6	Water tube. "National"	1	38	18½	60	4	27	140		
	1	Corliss Vertical	1	108	18½	264	3	50	140		
	1	Marine	1	86	20	200	2	38	140		
8	2	Horizontal return tube	1	60	14	98	3	25	90	Soft and hard Slack and Screenings	1.77
9	20	Horizontal return tube	1	60	16	66	4	30	70	Soft Coal. Estimated	2.00
10	2	Horizontal return tube	1	72	16	100	3½	27	80	Soft Coal	1.95
11	4	Horizontal return tube	1	60	16	54	3½	28	80	Soft Nut and Slack	
12	2	Horizontal return tube	1	72	16	92	4	25	80	Soft, Nut and Lump Coal	2.32
13	2	Water tube. "B & W."	1	33	18	48	4	Roney	110	Soft Nut Coal	2.00
14	1	Horizontal return tube	1	54	14	52	3	18	70	Soft Coal and Slack	2.05
	1	Horizontal return tube	1	54	14	64	3	18	70		
15	1	Horizontal return tube	1	52	12	68	3	25	75	Soft run of Mine Coal	1.90
	1	Horizontal return tube	1	54	12	64	3	25	75		
16	1	Horizontal return tube	1	72	14	86	4	..	85	Shavings and a litt'e	
	1	Horizontal return tube	1	72	12	86	4	..	85	Soft Coal	
17	6	Vertical, fire tube	1	60	15	180	2½	28.3	150	Soft Coal	3.35
18	8	Horizontal return tube	1	66	20	72	3½	25	95	Half each, Hard Pea and Soft Coal	2.55
19	11	Horizontal return tube	1	60	20	78	3	30.2	100	¾ Soft, ¼ Rice	2.68
	5	B. & W	3	36	23	126	4	60	70		
20	6	Harrison safety	..	..	..	..	..	40	100	150 H. P. each. Buckwheat	2.40
	8	Harrison safety	..	..	..	..	..	38.3	110	150 H. P. each. Buckwheat	2.40
21	9	Vertical, fire tube	1	60	15	184	2½	28.3	120	½ Soft, ½ Pea and Rice hard	2 57
22	8	Horizontal return tube	1	66	16	124	3	30	125	Cumberland Coal	3.10

It will be seen that in rated capacity the plants vary from 40 horse-power to 2,500 and in value per rated horse-power from $23 to $89 in steam power plants, or as high as $368 in water works pumping stations.

While the type of boiler used leans largely to the plain, old-fashioned return tubular, with the exception of the cotton mills, the types of engines are almost as varied as the number of plants.

In fuel, soft coal or slack of soft coal largely predominates, and a considerable use of mixtures of the latter with dust from the yards and hard coal slack will also be noticed, which is largely due to efforts to reduce the smoke nuisance.

In table III, under the general heads of "out-put," "operating expense" and "fixed charges," are shown all the items in detail for each plant, going to make up the total annual cost of power, and in table III a, will be found the items making up the cost per horse-power per hour.

The first column in table III, under "output," shows the average power developed for one year covering the number of days and hours per day shown in the third and fourth columns; and column 2 shows the percentage of the total rated capacity that the average power actually developed bears to the rated horse-power of engines, as shown in table II. The time in hours per day shown in column 4, is not in all cases the actual average per day for the year, but the regular time on which the plant was run during the year under consideration, therefore multiplying the figures in this column by the days actually run will not in all cases give as a result the total hours per annum shown in the sixth column, which are the actual hours run in each case.

In table III, under the headings of "operating expense," "fixed charges," and "cost per horse-power," the figures are the costs per annum for each item, while table III_A, gives the cost per horse-power per hour obtained by dividing the annual cost of each item by the number of hours run as shown in the sixth column.

In tables II, V and VI, the results from the different plants have been separated and classified according to the hours per diem during which they are run, making the broad distinction of 20 to 24 hour runs and 9 to 12 hour power, there are however two plants that, owing to wide difference of running time could not be brought under these headings, and they have therefore been placed by themselves in table VI.

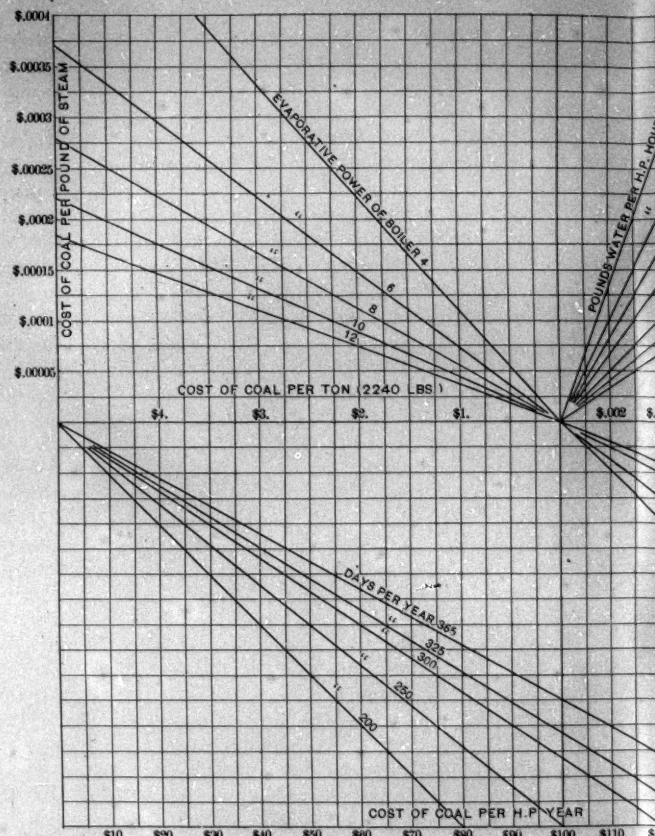
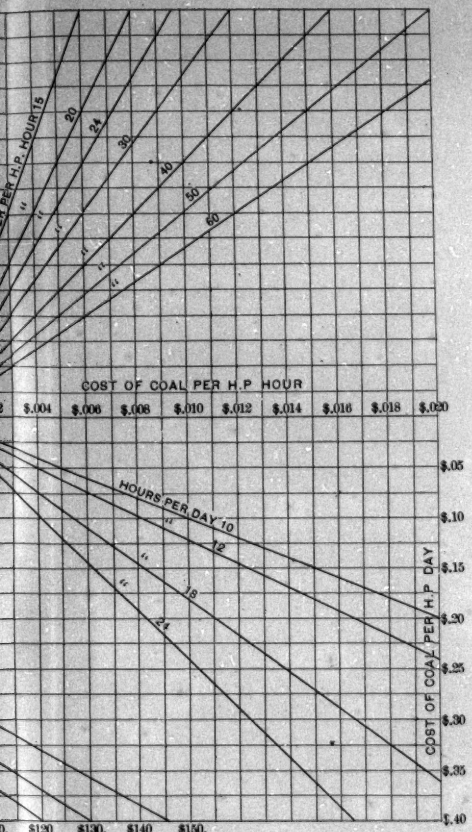


CHART FOR DETERMINING COST OF COAL PER HOR

From this diagram the cost of coal per H. P. per annum is calculated as follo

Beginning at "Cost of Coal per Ton" at left of centre of sheet, ascend ve Boilers," then follow horizontal line to the right to diagonal marked "Pounds Wat to diagonal marked "Hours per Day" and from this point follow horizontal line t "Days per Year." From this point of intersection follow vertical line downwa Coal per H. P. Year."



HORSE-POWER PER ANNUM.

s follows:

nd vertical line to diagonal marked "Evaporative Power of
a Water per H. P. Hour," then follow vertical line downward
ine to the left to point of intersection with diagonal marked
rnward to a scale at bottom of the diagram giving "Cost of

TABLE II. POWER PLANT EQUIPMENT, ENGINES, VALUES AND LABOR.

No. of plant.	ENGINES. No. of Engines.	Type.	How Run.	Cylinders. Diam high inches	Diam low inches	stroke inches	Rv'ls per min.	Rated H. P.	VALUES. Total power plant.	Per rated H. P.	LABOR. Engineers. No.	Engineers. Rate per mo.	Firemen, etc No.	Firemen, etc Rate per mo.	Purposes for which steam is used other than for power, from same boilers, at same time.
1	1	Corliss	non-condensing	22	..	48	80	380	$14,865	$39.12	2	$78	2	$60	Exhaust heating, during winter.
2	1	Cummer	condensing	22.1	..	42	78	250	11,000	44.00	2	78	2	45	
3	1	Corliss	non-condensing	16	..	36	86	125	18,300	89.27	1	125	2	48	Steam tables, elevator and other pumps.
	1	Slide Valve	used occasionally	12	..	20	162	80			2	62	.	..	
4	1	Slide Valve	non-condensing	12	..	16	125	40	2,337	58.42	1	65	.	..	Steam tables; exhaust for building in winter.
	1	Compound Automatic	non condensing	8	14	14	194	65							
5	1	Vertical	non-condensing	16 7/18	..	20	74	65	1,500	23.08	1	90	.	..	Steam tables and neighboring building.
6	1	Vertical Compound	condensing	15	30	20	60	100	10,143	46.16	1	125	1	52	Steam tables; heating building in winter.
	1	Straight Line	non-condensing	10	..	16	235	60			2	65	1	40	Elevator and other pumps.
	1	Ball	non-condensing	10	..	12	275	60							
7	1	Corliss Compound	condensing	30 3/4	56	60	68	1,500	100,000	40.00	1	100	4	55	
	1	Corliss Compound	condensing	26	42	48	75	1,000			2	75	4	50	
											2	50			
8	1	Wheelock	non-condensing	17	..	38	100	165	11,200	67.88	1	45	1	36	
9	2	Holly double Compound	condensing	36	72	48	16	....	632,000	287.90	1	167	9	61	
	1	Holly double Compound	condensing	33	66	48	16	....			3	87	2	40	
	2	Worthington Compound	condensing	38	66	50	10	....			7	40	6	40	
	1	Worthington Compound	condensing	29	50	50	10	....			7	45			
10	2	Holly Compound	condensing	12	24	22	21	....	40,478	367 98	1	100	2	45	
											1	75			
11	2	Holly Compound	condensing	12	24 1/4	22	19	....	28,000	254.54	1	100	2	48	Part of last year for electric power station in same building.
											1	50			
12	1	Slide Valve	non-condensing	28	..	36	78	300	9,500	31.66	1	78	1	45	For small electric light plant occasionally.
13	2	Compound Automatic	non-condensing	8	13 3/4	12	235	65	7,730	46.85	1	100	1	43	For elevator and other pumps and to help exhaust in winter.
	1	Westinghouse	non-condensing	..	..	..	..	35			2	65			
14	1	Buckeye	non-condensing	12	..	22	140	65	4,500	69.23	1	75	1	48	For heating ovens and part of building.
											1	56			
15	1	Slide Valve	non-condensing	12	..	12	280	80	3,000	37.50	1	48	.	..	To help exhaust in winter. Exhaust used for dry rooms all the year.
16	1	Wright	non-condensing	22 1/4	..	42	68	200	7,000	35.00	1	78	1	45	To help exhaust in winter. Exhaust used for dry rooms all the year.
17	1	Corliss trip. comp	condensing	24	1-34 / 2-36	60	62 1/2	1,200	57,500	47.92	1/2	100	2	35	1st asst. Eng. @ $32 and 1 coal wheeler @ $30.
18	1	Corliss dbl. tand. comp.	condensing	22	40	60	68	1,000	71,434	71.43	1	75	2	35	One oiler @ $35 for slashers and vapor.
19	1	Corliss double	1/4 condensing	22	..	60	54	600			1	75	2	39	Exhaust from one cyl. of Nos. 1 & 2 for slashers.
	1	Corliss double	1/2 condensing	22	..	60	64	600			1	100	2	32	Live steam for heating and vapor.
	1	Corliss cross comp	condensing	24	44	60	68	800			1	50	1	42	
	1	Corliss cross comp	condensing	22	40	60	65.8	500	146,550	58.75	2	42	3	36	Watchman @ $48.
20	1	Corliss cross comp	condensing	28	52	60	66 1/4	1,200			1	90	3	36	One coal wheeler at $30.
	1	Corliss double	3/4 condensing	28	..	60	57	800	110,000	55.00	2	36	2	26	Exhaust form slashers and vapor.
21	1	Corliss cross comp	condensing	28	52	72	63	1,400	68,789	49.14	1	100	2	38	Two wheelers @ $33.
22	1	Corliss cross comp	condensing	26	52	72	57	1,200	64,000	55.33	1	67	1	40	One fireman @ $24, one wheeler @ $47, steam for vapor and slashers.

TABLE III.

Annual Output and Cost per Horse-Power.

No of plant.	OUTPUT.						OPERATING EXPENSES.						FIXED CHARGES.					Cost per horse-power.
	Average H. P. develpd.	Per cent. of total engine capacity.	No. of days	Time per day. hrs.	Time per day. mins.	Hours per annum.	Fuel.	Wages	Supplies.	Repairs	Water.	Total.	Interest.	Depreciation.	Insurance.	Taxes.	Total.	
1	296.7	78	297	24	..	7,128	$26.20	$10.95	$1.68	$5.77	$0.96	$45.56	$2.55	$3.52	$1.07	$0.67	$7.81	$53.37
2	210.9	85	290	24	..	6,960	22.00	13.26	3.94	1.11	.....	40.33	2.61	2.80	1.50	.95	7.86	48.19
3	58 8	47	365	24	..	8,135	36.30	44.60	1.90	3.60	2.90	97.30	13 87	12.24	2.61	5.10	33.82	131 12
4	12 4	31	361	9	..	3,007	48.93	84.12	9.13	1.62	4.13	147.93	9 46	11.62	1.89	2.43	25 40	173.33
5	21.5	33	361	9	..	3.711	28.82	51.09	7.34	1.24	1.98	90.47	8.13	6.98	1.94	.75	17 80	108.27
6	70.4	32	363	23	..	7,461	34.00	55.07	5.09	5.40	2 13	101.69	5 77	9.24	4.62	1.13	20.78	122.45
7	1,345.5	54	365	11	..	4,008	11.75	8.93	.55	2.01	.07	23.28	3.71	5.21	.26	.24	9 42	32.70
8	129.3	78	365	12	27	4.544	18 25	9.82	.58	.72	.77	30.14	2.97	5.28	1.16	....	9 41	39 55
9	1,352.	62	365	24	..	8,760	13.76	13.00	2.74	3.53	....	33.03	13.10	12.78	3.53	....	29.41	62 14
10	36 7	33	365	24	..	8,327	36.71	81.62	8.70	10.22	....	137.25	44.10	43.40	1.30	7.80	96 70	233.95
11	42.4	39	365	24	..	8,755	26.54	54.49	3.96	1 39	....	86.38	26.41	28.29	1.43	7 07	63.20	149 58
12	173.	58	313	3	..	939	11.98	8.53	1 05	.88	.22	72.66	3 40	3.22	1.46	.55	8.63	31.29
13	53.	32	309	15	30	4,790	24.43	25.50	2.35	1.93	2.73	56.94	7 29	9.57	1.19	1.46	19.51	76.45
14	20.9	32	365	24	..	8,110	49.30	55 30	8 83	3.59	6.10	123.12	10.79	13.33	2.15	2.15	28.42	151.54
15	32.9	41	330	10	20	3,410	9 58	8.74	2.92	1 22	.10	22.56	1.88	3.76	.19	....	5.83	28.39
16	166.7	84	313	9	50	3,073	5.46	7.48	1.36	.53	.31	15.19	1 57	2.02	.74	.14	4.47	19.66
17	1,174 8	98	306	9	40	2,958	7.62	2.82	.54	.21	....	10.19	2.10	2.35	.35	.60	5.50	15.69
18	986.	93	307	9	40	2,963	8.64	2.20	.62	.27	....	11.73	3.68	3.93	.20	.96	8.77	20.50
19	2,422.	97	306	9	40	2,958	11.12	3.18	.81	.56	....	15.67	2.88	2.85	.25	.75	6 73	22.40
20	1,909 7	95	306	9	40	2,958	8.76	2.26	.82	1.56	....	13.40	2.62	3.21	.22	.58	6.63	20.03
21	1,278 7	91	293	9	40	2.831	7 40	2.41	.46	.22	....	10.49	2.57	2.96	.16	.54	6.23	16.72
22	1,010.86	84	306	9	40	2,958	8 89	2.24	1.35	3.22	....	15.70	3.04	3.36	.24	1.10	7.74	23.44

TABLE IIIa.

Cost per Horse-Power per Hour.

No. of Plant.	OPERATING EXPENSE.						FIXED CHARGES.					Cost per Horse-Power
	Fuel.	Wages.	Supplies.	Repairs.	Water.	Total.	Interest.	Depreciation.	Insurance.	Taxes.	Total.	
1	$.00367	$.00154	$.00024	$.00081	$.00013	$.00640	$.00036	$.00049	$.00015	$.00009	$.00109	$.00749
2	.00316	.00191	.00057	.00016	.....	.00580	.00037	.00040	.00022	.00014	.00113	.00693
3	.00445	.00548	.00122	.00044	.00036	.01195	.00171	.00151	.00032	.00063	.00417	.01613
4	.01594	.02740	.00297	.00053	.00135	.04986	.00308	.00370	.00062	.00079	.00818	.05648
5	.00778	.01376	.00198	.00033	.00053	.02440	.00218	.00188	.00052	.00020	.00478	.02818
6	.00455	.00738	.00068	.00072	.00028	.01361	.00077	.00124	.00062	.00015	.00278	.01641
7	.00296	.00222	.00014	.00051	.00002	.00585	.00092	.00131	.00006	.00006	.00235	.00820
8	.00402	.00216	.00013	.00016	.00017	.00664	.00205	.00116	.00026	.....	.00207	.00871
9	.00157	.00148	.00031	.00040	.....	.00377	.00149	.00146	.00040	.....	.00336	.00713
10	.00441	.00981	.00104	.00123	.....	.01650	.00530	.00522	.00075	.00094	.01161	.02811
11	.00303	.00622	.00045	.00016	.....	.00986	.00302	.00323	.00016	.00081	.00722	.01708
12	.01276	.00910	.00112	.00094	.00023	.02415	.00362	.00343	.00155	.00058	.00918	.03333
13	.00511	.00532	.00049	.00040	.00057	.01190	.00152	.00199	.00025	.00030	.00406	.01596
14	.00608	.00683	.00109	.00044	.00075	.01520	.00133	.00164	.00026	.00026	.00350	.01868
15	.00281	.00256	.00085	.00036	.00003	.00661	.00055	.00110	.00005	.....	.00171	.00832
16	.00178	.00244	.00044	.00018	.00011	.00494	.00051	.00065	.00024	.00005	.00145	.00639
17	.00158	.00262	.00018	.00027	.....	.00345	.00078	.00079	.00008	.00021	.00186	.00531
18	.00292	.00074	.00021	.00009	.....	.00396	.00124	.00133	.00006	.00032	.00295	.00691
19	.00377	.00107	.00027	.00019	.....	.00530	.00098	.00096	.00008	.00025	.00227	.00757
20	.00296	.00076	.00028	.00053	.....	.00453	.00089	.00109	.00007	.00019	.00224	.00677
21	.00261	.00085	.00016	.00008	.....	.00370	.00091	.00104	.00005	.00020	.00220	.00590
22	.00301	.00076	.00046	.00109	.....	.00532	.00103	.00114	.00008	.00037	.00262	.00794

In considering the plants under these general divisions, it must still be borne in mind that while they are classed under the same heading in hours per diem, they are by no means all run the same number of days per year, and therefore the total hours per annum during which the plant was run becomes the only correct basis on which to compute the cost for comparison.

In the above tables the unit costs per year, per day and per hour, have been computed and placed in parallel columns, the first and last being from table III, while the cost per day is deducted from the actual number of days run, divided into the cost per annum.

TABLE IV.

UNIT COSTS FOR 20 TO 24 HOUR POWER.

Number of Plant.	Average Horse-Power Developed.	COSTS.		
		Per Horse-Power, Year.	Per Horse-Power, Day.	Per Horse-Power, Hour.
1	296.7	$53.37	$.1797	$.00749
2	210.9	48.19	.1662	.00693
3	58.8	131.12	.3592	.01613
6	70.4	122.45	.3355	.01641
9	1352.0	62.44	.1711	.00713
10	36.7	233.95	.6409	.02811
11	42.4	149.58	.4098	.01708
14	20.9	151.54	.4152	.01868

TABLE V.

UNIT COSTS FOR 9 TO 12 HOUR POWER.

Number of Plant.	Average Horse-Power Developed.	COSTS.		
		Per Horse-Power, Year.	Per Horse-Power, Day.	Per Horse-Power, Hour.
4	12.4	$173.33	$.4801	$.05648
5	21.5	108.27	.3000	.02918
7	1345.5	32.70	.0896	.00820
8	129.3	38 55	.1084	.00871
15	32.9	28.39	.0860	.00832
16	166.7	19.66	.0628	.00639
17	1174.8	15.69	.0513	.00531
18	926.0	20.50	.0669	.00691
19	2422.0	22.40	.0732	.00757
20	1909.7	20.03	.0655	.00677
21	1278.7	16.72	.0571	.00590
22	1010.8	23.44	.0767	.00794

In tables VII, VIII and XI, and under the same general headings as to hours run per diem, as in tables IV, V and VI, a comparison is made of the amount of power used as compared with

TABLE VI.

UNIT COSTS FOR 3 HOUR POWER AND FOR 15½ HOUR POWER.

Hours Run.	Number of Plant.	Average Horse-Power Developed.	COSTS.		
			Per Horse-Power, Year.	Per Horse-Power, Day.	Per Horse-Power, Hour.
3	12	173	$31.29	$.1000	$.03333
15½	13	53	76.45	.2473	.01596

the actual rated capacity and under the items of expense are shown the total operating expense per hour, the total fixed charges per hour and in the last two columns the percentage each is of the total cost.

TABLE VII.

COMPARISON OF POWER AND EXPENSES.

20 TO 24 HOURS.

No. of Plant.	Rated Capacity, H. P.	Average Used H. P.	Per cent. Used of Capacity.	EXPENSE PER H. P. HOUR.			
				Operating.	Fixed.	Per cent. Operating of Total.	Per cent. Fixed of Total.
1	380	296.7	78	$.00640	$.00109	85	15
2	250	210.9	85	.00580	.00113	84	16
3	205	58.8	47	.01195	.00417	74	26
6	220	70.4	32	.01361	.00278	83	17
9	2195	1352.0	62	.00377	.00336	53	47
10	110	36.7	33	.01650	.01161	58	42
11	110	42.4	39	.00986	.00722	57	43
14	65	20.9	32	.01520	.00356	81	19

TABLE VIII.

COMPARISON OF POWER AND EXPENSES.

9 HOURS TO 12 HOURS.

No. of Plant.	Rated Capacity, H. P.	Average Used H. P.	Per cent. Used of Capacity.	EXPENSE PER H. P. HOUR.			
				Operating.	Fixed.	Per cent. Operating of Total.	Per cent. Fixed of Total.
4	105	12.4	31	$.04800	$.00828	86	14
5	65	21.5	33	.02440	.00478	84	16
7	2500	1345.5	54	.00585	.00235	71	29
8	165	128.3	78	.00664	.00207	76	24
15	80	32.9	41	.00661	.00171	79	21
16	200	166.7	84	.00494	.00145	77	23
17	1200	1174 8	98	.00345	.00186	65	35
18	1000	936.0	93	.00306	.00205	57	43
19	2500	2422.0	97	.00530	.00297	71	30
20	2000	1909.7	95	.00453	.00284	67	33
21	1400	1278.7	91	.00370	.00290	63	37
22	1200	1010.8	84	.00532	.00262	67	33

TABLE IX.

COMPARISON OF POWER AND EXPENSES.
3 HOURS AND 15½ HOURS.

No. of Plant.	Hours Run.	Rated Capacity H. P.	Average Used H. P.	Per cent. Used of Capacity.	EXPENSES PER H. P. HOUR.			
					Operating.	Fixed.	Per cent. Operating of Total.	Per cent. Fixed of Total.
12	3	300	173	58	.02415	.00918	72	28
13	15½	165	53	32	.01190	.00406	75	25

Referring back to table IV and taking up the plants in order, it will be well to discuss each one, in-so-far as may be necessary to explain why it differs in cost from another similar plant of which test is also given.

Commencing then with plants No. 1 and 2, being used for similar purposes, the first being somewhat larger in capacity than the second.

The first has a Corliss, non-condensing engine and boilers of a very efficient vertical type, while the second has old and comparatively inefficient return tubular boilers, but a good type of engine, running condensing, which accounts for the cost being somewhat less than for plant number one.

It may be said that during the test the first of these plants was found to be using a great deal more coal when the night fireman was on duty, than the day fireman used in the same length of time, and for an average of two horse-power in excess over that developed during the night. Since the test, this has been remedied and it is said that the plant is now running at a very considerable saving over its former condition. The waste of coal as mentioned above, is one of the items that cannot be included in any theoretical computation, but is too common in practice.

Plants 3 and 6, both run similar types of business, the first getting its power from a fine simple Corliss engine kept in the best of order, while the other uses one very old type of engine running compound condensing, and two small high speed engines, running at high pressure. Both plants are well kept and the final results in costs per horse-power per hour is seen to vary but .0003.

The next three cases 9, 10, 11 are three pumping stations

under city control, and while the total cost seems high, it must be remembered that fixed charges account for a good part of the entire expense, and in making comparisons between plants of this kind and other power, it will be more fair to compare operating expenses only, and in that case the showing while high is not so much higher than for other plants of a similar capacity as to be startling.

The last case in this division, No. 14, was the only one of the nature of business carried on and the only detail given will be to say that it had a Buckeye engine, kept in the best of order.

Plants Nos. 4 and 5, in table v, are used in similar business, and in spite of the fact that the first has by far the better plant, the cost is seen to be a great deal higher than in the second case, and mainly for the reason that a larger average output is obtained from the latter plant.

Case No. 7 in the same table is one in which the circumstances were such as to enable the determination of cost with extreme accuracy, the output being uniform and constant and the accounts most accurately kept. The cost is somewhat higher than it might be, owing to rather low ratio of output to capacity, but this has since been remedied and the unit cost materially reduced.

Plant No. 8 is one that will answer for a type of hundreds of small electric lighting stations in the United States, and the test is only remarkable in the variety of output, making it necessary to do a very large amount of calculation in order to arrive at anything like reasonably correct results. Fortunately for the purpose, ampere records had been kept of the incandescent part of the output, as well as a clear record of the number of arc lamps run, together with the time of running for each night of the year.

By making an indicator test of the engine, and at the same time recording the amperes and volts at the switchboard, it was easy to arrive at the average power for a complete run and thus to establish a ratio of steam power to electrical output for the entire year, and by means of the ratio converting it into horse-power, an average power for the entire year was determined.

The resulting cost per horse-power is surprisingly low and is due to several things, first, low rate of wages; second, just as little labor as could run the plant, and third, cheap fuel.

A calculation of the cost of the electric output in this plant

shows it to be not nearly so economical as might with reason be expected from the low cost of steam power, and is due to the low average efficiency of the plant, caused by running for many hours at light loads.

Plant No. 15, is one of that type of plants that uses steam for power purposes, more as an incident of the manufacture than as one of the prime factors in cost.

Steam for drying goods is the chief factor in plants of this kind, and in this case all the exhaust from the engine and in cold weather much live steam is used for drying purposes.

Plant No. 16, like the last one, uses a great proportion of its steam for drying purposes, and an additional factor for low power cost is, that nearly all fuel for day use is the waste wood and shavings from the manufacture. Add to this the fact that the machinist acts as engineer, and the engine is of good size and located in the machine repair shops and it will be seen that most of the factors in the case make a very low cost of power.

Plants Nos. 17 to 22 inclusive, are large cotton mills, in an eastern state. The statement made in the early part of this paper, seems to be borne out that, while it might be thought that mills of this nature using as large units of power as do these, and in a business so near alike for all, would perhaps show a more uniform cost of power, still vary a somewhat larger amount than would be practicable to average.

The cost of the lowest, No. 17, is $00531 per horse-power hour and the highest, No. 22, $00794, a difference of nearly 50 per cent increase over the first mentioned plant. To be sure, the first named plant (No. 17) is a new style Corliss, 4 cylinder, triple expansion, condensing engine, while the last (No. 22) is of the cross-compound condensing Corliss type.

Of course, it is readily seen that the extra cost could not be in fuel efficiency, and by reference to table III, it will be seen that the difference is in "supplies" and "repairs" to a very large extent, caused by a charge of part of the expense of replacing the whole bank of boilers. This is one of the items of cost that so often happen in steam plants, and the charge is seldom included in figuring the cost of power.

Comparing No. 17 with No. 21, the total cost per hour for the former is $.00531 and for the latter $.0059, a difference of $.00059, or 11 per cent of the first named plant.

Again referring to table III, another perhaps unexpected re-

sult is found, *i. e.* the fuel cost for the triple expansion engine is higher than in the other (No. 21), which is a Corliss cross-compound condensing engine.

As both plants use Manning boilers that are presumably of like efficiency, a reference to table I shows that the coal used in No. 17 cost $3.35 per ton, while the mixture used in No. 21, cost but $2.57 and the difference in quantity used that may have been due to higher engine economy, seems not to have made up for the difference in price.

Taking up the wages cost for these six plants, an examination of tables III and III a, shows a very considerable variation in that item, due to a number of different factors: for instance, No. 22 has but one engineer, with not even an oiler, but the number of firemen used brings up the cost to a trifle more than on No. 17, where the one engineer divides his time equally between the plant examined and another one, and therefore equally divides the cost, an oiler looking directly after the care of the engine; and the divisor (amount of power developed) is greater in the first case, thus materially reducing the unit cost. The labor cost in steam power can be made one of the greatest variables in it and when it is found to be a fact that one engineer at say $3.00 per day, can and does successfully run an engine developing over a thousand horse-power, and yet no less cost than this is required for running a plant of say 200 or even 100 horse-power, it is readily seen that the unit cost differs materially in the two cases and will vary proportionally between the two limits. Of course this is not advanced as new in theory but the writer wishes to call rather closer attention to the point than seems to have been given it in the past.

In table VI, the first plant No. 12, is a large grain elevator in which power is used spasmodically and averages but 3 hours out of the 24 the year round. This power varies in amount to a great extent, running at times as low as 43 horse-power and again with the "marine leg" on, and other "lofters" as high as 250 horse-power may be in use for a short time. The average 173 horse-power is somewhat higher than might be expected with the entire disuse of the marine leg in winter, and only the inside legs going during that time, but it checks well with all the tests made on the plant.

Plant No. 13 is run for 15½ hours every working day of the year and in spite of the fact that the engine and dynamo plant

is in duplicate, the cost per horse-power is quite low; this is mainly due to extremely good management and careful accounting. Power is mainly used for running electric lights and one or two small motors. Steam is used for power and for an elevator and other pumps. An accurate record is kept of the weight of coal used each day, and the reading of the ampere and voltmeters is registered all day long at hourly intervals, thus enabling a quite accurate estimate to be made of the average power, by determining the ratio of cylinder power to ampere readings.

While the above 22 plants are the only ones on which tests available for this paper were carried out, many others were examined during the time, and while it may be said that in most plants fairly accurate tests may be made, some are found in which it is next to impossible to arrive at anything like accurate results.

Until one makes a business of examining power plants with an idea of learning the unit cost of power, it is impossible to judge adequately of the varying conditions obtaining and therefore of the fact that any possible statement of an average cost is misleading.

It has been the writer's experience that one of the greatest factors for varying the cost of steam power in a given plant is to be found in the fire room.

In but few plants is this part of the expense found to receive the attention it should have to obtain the best results; and as a whole, the men employed at the work of firing are of a class that seldom runs to brains, and unless pushed to it by the management, the engineer is prone to exercise only a nominal supervision over the department. When a fireman on one shift can use nearly twice as much coal doing the same work as the fireman on the other shift as was found in one case, it is time the engineer was disposed of or new methods arranged.

In plants developing a low amount of power, say less than 100 horse-power, as a large majority of them do, the labor item due to varying conditions of the business, becomes a very important factor, and one in which great saving can be made by re-arrangement of power supply.

In order to make this paper of greater value, the writer has thought it well to add the results of estimates by other investigators and, as coal is the only item that varies to a great extent

in unit price, it has been thought best to bring that item to the same price per ton, and, as the ton used in the neighborhood where most of the tests were made is 2,000 pounds, all weights and prices have been reduced to a cost of $3.00 per 2,000 pounds, delivered.

Tables X to XVII inclusive, are the results of the tests by the writer, classified by types of plant, and reduced to coal at $3.00 per 2,000 pounds. These tables show the number of the plant as given in the previous tables, the hours run per diem, the average power developed, operating, fixed and total expense per hour per horse-power.

Table X, shows the costs for slow speed non-condensing engines, irrespective of the size or number of hours run per diem. Although an average is taken of these, it is of course of little value as the costs vary not only by reason of the amount of power developed but from the number of hours run per diem, and the variety of each of these conditions is such that each item could as well be placed by itself.

Table XI shows results for high speed automatic engines, which are also assembled irrespective of time of running or power developed and show very uneven costs.

Tables XII and XIII include but one plant each, and are therefore of little use for comparison, excepting as showing the general variation of cost.

TABLE X.

COAL REDUCED TO $3.00 PER 2,000 LBS.
SLOW SPEED. NON-CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
1	24	296.7	$.00821	$.00109	$.00930
3	23	58.8	.01343	.00417	.01760
5	9	21.5	.02865	.00478	.03343
8	12	129.3	.00692	.00207	.00899
16	10	166.7	.00591	.00145	.00736
12	3	173.	.02789	.00918	.03707
Averages.	.....	.....	$.01517	$.00379	$.01896

TABLE XI.

COAL REDUCED TO $3.00 PER 2,000 LBS.
HIGH SPEED. AUTOMATIC NON-CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
14	24	20.9	$.01802	$.00350	$.02152
4	9	12.4	.05686	.00828	.06514
15	10	32.9	.00824	.00171	.00995
13	15	53	.01446	.00406	.01852
Averages..	....	.....	$.02439	$.00439	$.02878

TABLE XII.

COAL REDUCED TO $3.00 PER 2,000 LBS.
SLOW SPEED CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
2	24	210.9	$.00785	$.00113	$.00898

TABLE XIII.

COAL REDUCED TO $3.00 PER 2,000 LBS.
COMBINED. COMPOUND-CONDENSING AND AUTOMATIC NON-CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
6	23	70.4	$.01573	$.00273	$ 01851

Table XIV, shows like results for three pumping stations, and one gets a very good idea of the vast difference in unit cost of power when developed is widely varying quantities; the first plant, developing 1,352 horse-power, and the other two less than 50 horse-power each, the difference in cost between the highest and the lowest being as $.007 is to $.03048.

TABLE XIV.

COAL REDUCED TO $3.00 PER 2,000 LBS.
PUMPING ENGINES, COMPOUND CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
9	24	1352.	$.00455	$.00336	$.00791
10	24	36.7	.01887	.01161	.03048
11	24	42.4	.01149	.00722	.01871
Averages..	... ...	....	.01174	.00739	.01913

In table XV, is shown the cost for four large plants using slow speed compound condensing engines. This type of plant is perhaps the most common of modern plants in use for large quantities of power, and is one on which perhaps the most and best estimates have been made, and therefore most easily compared with other tables.

TABLE XV.

COAL REDUCED TO $3.00 PER 2,000 LBS.
SLOW SPEED COMPOUND CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
7	11	1345.5	$.00901	$.00235	$.01136
18	10	926.0	.00447	.00295	.00742
21	10	1278.7	.00414	.00220	.00634
22	10	1010.8	.00522	.00262	.00784
Averages..	... .	....	.00571	.00253	.00824

Table XVI, shows the result in one plant using a large triple compound engine of special type, and one of the items tending to low cost in this instance, is that but half the engineer's time is chargeable to this particular plant; another being the low fixed charge owing to very close buying by the management. The cost of power here will be seen to be less than generally estimated.

TABLE XVI.

COAL REDUCED TO $3.00 PER 2,000 LBS.
SLOW SPEED TRIPLE COMPOUND CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
17	10	1174.8	$.00318	$.00186	$.00504

Table XVII, shows the results in two mixed plants of large size, both cotton mills. In both cases about half the plant consists of the best type of compound condensing engines, while the remainder is made up of the old-fashioned double Corliss part condensing type, the exhaust from one end of each cylinder being generally used for purposes of heating about the mills. In passing, it may be well to say that most of the modern cotton mill plants use steam for heating direct from the boiler through pressure reducing valves, and not from any part of the exhaust of the engines.

TABLE XVII.

COAL REDUCED TO $3.00 PER 2,000 LBS.
COMBINED, COMPOUND CONDENSING AND SIMPLE CONDENSING.

Number of Plant.	Hours Run.	Average Power.	EXPENSES.		
			Operating.	Fixed.	Total.
19	10	2422.	$.00460	$.00227	$.00687
20	10	1909.7	.00527	.00224	.00751
Averages..	.....	.....	$.00494	$.00225	$.00719

COMPARISONS.

Of modern investigations of the cost of power, none stand higher than those of Dr. C. E. Emery in a paper before the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, March 21st, 1893, I have therefore thought it well to include here such parts of the tables as will afford a chance for comparison with the work of the writer and that of others. The investigation by Dr. Emery in this particular case was confined to the large unit of 500 net horse-power and its application must be limited to that amount as any departure will be found to vary the results.

Key to Tables XVIII, XIX, XX and XXI.

Style of Engine.

A. Simple High Speed Non-Condensing.
B. Simple Low Speed Non-Condensing.
C. Compound High Speed Non-Condensing.
D. Special Triple Compound High Speed Non-Condensing.
E. Simple High Speed Condensing.
F. Simple Low Speed Condensing.
G. Compound High Speed Condensing.
H. Compound Low Speed Condensing.
I. Special Triple Compound High Speed Condensing.
J. Triple Compound, Low Speed Condensing.
K. Triple Compound, Low Speed Condensing.
L. Ditto, for probable maximum results.

As Dr. Emery's computations are made on net power and with coal at 2,240 pounds per ton, it has been necessary to reduce his figures to indicated horse-power and coal at 2,000 pounds per ton, the results being found in tables XVIII and XIX following. Where necessary to bring the items of expense under the same heads, changes have been made in his tables so that direct comparison of items may be made.

Table XVIII shows itemized costs for 10 hour power per annum and in tables XX and XXI the totals have been reduced to cost

TABLE XVIII.

Emery's Tables Reduced to Indicated Horse-Power and Coal at $3.00 per 2,000 Lbs. 3,080 Hours Run.

Style of Engine.	OPERATING EXPENSE.				FIXED CHARGES		Total.	Total Cost.
	Coal.	Labor.	Repairs and Supplies.	Total.	Insurance, Taxes & Renewals	Interest.		
A	$19.70	$4.41	$2.73	$26.84	$2.72	$5.90	$8.62	$35.46
B	17.34	4.04	2.28	23.66	2.82	6.13	8.95	32.61
C	15.54	3.84	2.73	22.11	2.52	5.49	8.01	30.12
D	14.35	3.68	2.73	20.76	2.78	6.03	8.81	29.57
E	13 15	3 51	2.73	19.39	2.32	5.04	7.36	26.75
F	11.94	3.31	2.28	17.53	2 46	5.35	7.81	25.34
G	11.05	3.35	2.73	18.03	2.30	5.16	7.57	25.60
H	10.76	3.14	2.28	16.18	2.50	5.43	7.93	24.11
I	10 13	3.10	2.73	15.98	2.53	5.49	8.02	24.00
J	9.36	2.98	2.28	14.82	2.82	6.11	8.93	23 75
K	8.96	2.90	2.28	14.14	3.02	6.56	9.58	23.72
L	7.50	3.36	2.28	13.14	2.98	6.45	9.43	22.57

per hour per horse-power in order to conform with the argument of the writer that the only correct safe statement is cost per hour and not per annum.

TABLE XIX.

EMERY'S TABLES REDUCED TO INDICATED HORSE-POWER AND COAL AT $3.00 PER 2,000 LBS. 7,300 HOURS RUN.

Style of Engine.	OPERATING EXPENSE.				FIXED CHARGES		Total.	Total Cost.
	Coal.	Labor.	Repairs and Supplies.	Total.	Insurance, Taxes & Renewals.	Interest.		
A	$44.70	$10.45	$6.47	$61.62	$2.72	$5.90	$8.62	$70.24
B	39.20	9.57	5.38	54.15	2.83	6.13	8.96	63.11
C	35.20	9.11	6.47	50.78	2.53	5.49	8.02	58.80
D	32.50	8.72	6.47	47.69	2.78	6.02	8.80	56.49
E	29.70	8.34	6.47	44 51	2.32	$5.04	7.36	51.87
F	27.10	7.84	5.38	40.32	2.46	5.35	7.81	48.13
G	27.10	7.93	6.47	41.50	2.39	5.17	7.56	49.06
H	24.30	7.45	5.38	37.13	2.50	5.44	7.94	45.07
I	22.90	7.38	6.47	36.72	2.53	$5.49	8.02	44.74
J	21.64	7.07	5.38	34.09	2.81	6.14	8 95	43.04
K	20.30	6.85	5.38	32.53	3.02	6.57	9.59	42.12
L	16.93	7.98	5.38	30.29	2.98	6.44	9.42	39.71

TABLE XX.

COST PER HORSE POWER HOUR, FROM EMERY'S TABLES. 3,080 HOURS RUN.

Style of Engine.	Operating Expenses.	Fixed Charges.	Total Cost.
A	$.00870	$.00280	$.01150
B	.00769	.00291	.01060
C	.00719	.00261	.00980
D	.00675	.00286	.00961
E	.00630	.00239	.00869
F	.00570	.00254	.00824
G	.00587	.00246	.00833
H	.00526	.00258	.00784
I	.00520	.00261	.00781
J	.00482	.00290	.00772
K	.00460	.00311	.00771
L	.00428	.00307	.00735

In a discussion of a paper before the American Society of Mechanical Engineers, Mr. Samuel Webber took occasion to state the itemized cost of steam power as developed in a Fall River yarn mill and the results are here given in tables XXIII and XXIV with coal reduced to $3.00 per 2,000 pounds.

The totals will be found to agree fairly well with those from

TABLE XXI.

Cost per Horse-Power, Hour, from Emery's Tables. 7,300 Hours Run.

Style of Engine.	Operating Expenses.	Fixed Charges.	Total Cost.
A	.00845	.00122	.00967
B	.00741	.00123	.00864
C	.00695	.00110	.00805
D	.00652	.00121	.00773
E	.00610	.00101	.00711
F	.00551	.00107	.00658
G	.00508	.00103	.00671
H	.00508	.00109	.00617
I	.00502	.00110	.00612
J	.00466	.00123	.00589
K	.00445	.00131	.00576
L	.00414	.00129	.00543

Cost of Power, from Table in Engineering Magazine, by Dr. Emery. Coal Reduced to $3.00 per 2,000 Pounds. 3,080 Hours.

	Net Horse-Power.	Cost per H. P. per Hour.
Ordinary non-condensing	10	$.02570
Automatic Cut-off, non-condensing	75	.01306
Automatic Cut-off, condensing	140	.01060
Compound Condensing	250	.00856
Triple Compound Condensing	500	.00727

TABLE XXIII.

Cost of Power in a Fall River Yarn Mill. Samuel Webber. Coal Reduced to $3.00 per 2,000 Lbs.

	Cost per H. P. per annum.	Cost per H. P. per hour.
Operating Expenses.		
Fuel	$9.20	$ 00299
Wages	2.23	.00072
Repairs	1.57	.00051
Supplies	.31	.00010
Total	$13.31	$.00432
Fixed Charges.		
Interest, 5 per cent	$3.15	$.00102
Depreciation, 5 per cent	3.15	.00102
Insurance, non charged	....	....
Taxes, 1 per cent	.32	.00010
Total	$6 62	$.00214
	$19 93	$.00646

similar plants, although no insurance has been taken into account; if $.00007 be added, the result will give a direct comparison with other estimates.

TABLE XXIV.

COST OF POWER IN GLOBE YARN MILLS, No. 3. FALL RIVER. COAL REDUCED TO $3.00 PER 2,000 LBS. SAMUEL WEBER.

	Cost per H. P. per annum.	Cost per H. P. per hour.
OPERATING EXPENSE.		
Fuel	$10 73	$ 00349
Wages	2.89	.00094
Repairs	1.62	.00053
Supplies	.40	.00013
Total	$15.64	$.00509
FIXED CHARGES.		
Interest, 5 per cent	$3.23	$.00105
Depreciation, 5 per cent	3.23	.00105
Insurance none, charged	....	.....
Taxes 1 per cent	.32	$.00011
Total	$6.78	$.00221
	$22.42	$.00730

Table XXV, gives the result of a test made by Mr. R. S. Hale, expert for the Steam Users Association of Boston. Although

TABLE XXV.

COST OF POWER IN A LARGE COTTON MILL. R. S. HALE, BOSTON. COAL REDUCED TO $3.00 PER 2,000 LBS.

	Cost per H. P. per annum.	Cost per H. P. per hour.
OPERATING EXPENSES.		
Fuel	$6.92	$.00233
Wages	2.51	.00084
Repairs	.50	.00017
Supplies	.45	.00015
Total	$10.38	$.00349
FIXED CHARGES.		
Interest	$2.90	$.00097
Depreciation	2.40	.00081
Insurance	.22	.00007
Taxes	.69	.00023
Total	$6.21	$.00208
	$16 59	$.00557

the actual result was somewhat higher than here shown, owing to a higher price of coal; the result with coal reduced to the common standard is seen to be very low.

One of the plants instanced in a paper by Mr. May, before the American Society Mechanical Engineers, was the pumping engine of the North Point plant of the Milwaukee water works. As mentioned in a previous paragraph, it is not quite fair to compare water works plants with those used for other purposes, as the fixed charges are almost always high, and the labor necessary for the safety of fire service, etc., is higher than in ordinary plants. Still, as this plant was at the time the most economical steam machine in use, it is thought best to include it here. The net cost is seen to be well within limits of other estimates and is even lower than usual, owing probably to the fact of exceedingly high duty. If figures were obtainable, it would be very interesting to compare the results shown in table XXVI with similar costs on the Chestnut Hill pumping engine built by Mr. Leavitt, which has since surpassed in economy the North Point engine.

TABLE XXVI.

COST FOR YEAR 1892 OF RUNNING PUMPING ENGINES AT NORTH POINT PLANT OF THE MILWAUKEE WATER WORKS. COAL REDUCED TO $3.00 PER 2,000 POUNDS.

	Cost for the Year. 6,980 Hours.	Cost per H. P. per annum.	Cost per H. P. per Hour.
OPERATING EXPENSES:			
Fuel	$9,266.88	$16 54	$.00237
Wages	10,680.00	19.66	.00273
Repairs	414.00	.74	.00011
Supplies	754.00	1.35	.00019
	$21,114.88	$37.69	$.00540
FIXED CHARGES:			
Interest—5 per cent. on $72,500.	3,625.00	6.47	.00093
Depreciation—4 per cent. on $72,500	2,900 00	5.17	.00074
	$6,525.00	$11.64	$.00167
Total Cost	$27,639.88	$49.33	$.00707

In a paper read before the New York meeting of the American Society of Mechanical Engineers, and published in volume XI, of its *Transactions*, Mr. Chas T. Main of Lawrence, Mass. has

TABLE XXVII.

Cost of Steam Power per Annum.

From Tables of Chas. T. Main, Lawrence, Mass.

1,000 H. P. Engines.	Coal $3.00 per 2 000 lbs.	Wages.	Repairs.	Supplies.	Total Operating.
Compound	$8.28	$3.48	$1.17	$0.77	$13 70
Condensing	11 82	3.54	1.16	.68	17.20
High Pressure	14.20	3.85	1.17	.62	19.34

1,000 H. P. Engines.	Interest.	Depreciation	Insurance.	Taxes.	Total Fixed.
Compound	$2.92	$2.52	$0.26	$0.66	$6.36
Condensing	2.89	2.56	.26	.65	6.36
High Pressure	2.93	2.63	.27	.66	6.49

Total Cost per H. P. per Annum. (308 Days.)

1,000 H. P. Engines.	Operating.	Fixed.	Total.
Compound	$13.70	$6.36	$20.06
Condensing	17.20	6.36	23.58
High Pressure	19.84	6.49	26.33

TABLE XXVIII.

Cost of Steam Power per Hour per Horse-Power.

3,157 Hours. From Tables of Chas. T. Main, Lawrence, Mass.

1,000 H. P. Engines.	Coal @ $3.00 per 2,000 lbs.	Wages.	Repairs.	Supplies.	Total Operating.
Compound	$.00268	$.00112	$.00037	$.00024	$.00435
Condensing	.00375	.00112	.00037	.00022	.00546
High Pressure	.00459	.00122	.00037	.00020	.00629

1,000 H. P. Engines.	Interest 5 per cent.	Depreciation	Insurance.	Taxes.	Total Fixed.
Compound	$.00093	$.00080	$.00008	$.00021	$.00202
Condensing	.00092	.00031	.00008	.00021	.00202
High Pressure	.00093	.00033	.00008	.00021	.00205

Total Cost per Horse-Power per Hour.

1,000 H. P. Engines.	Operating.	Fixed.	Total.
Compound	$.00435	$.00202	$.00637
Condensing	.00546	.00202	.00748
High Pressure	.00629	.00205	.00834

developed to a most interesting degree, the cost of steam power for various costs of coal and where the exhaust from engines is used in varying quantities. He has divided the engines into three types or classes, *i. e.*, compound, condensing and high pressure, which are the three types most used in his locality, which is largely a centre for the manufacture of textiles. He has also stated the costs for engines of 500, 1,000, 1,500 and 2,000 horse-power capacity for each type and the results are very interesting, but too elaborate to be included in full in this paper.

I have, however, in tables XXVII and XXVIII assembled the unit costs for the various items, reducing the item of coal to the standard, for an engine of 1,000 horse-power of the three types, and with no exhaust steam used; in the first table, for the year, and in the second, per hour; the results will be found to agree fairly well with others.

TABLE XXIX.

COMPARISON OF DIFFERENT ESTIMATES.

LARGE, COMPOUND CONDENSING ENGINES.

	Cost per H. P. per Hour.
Emery, A. I. E. E., for 3,080 hours, table XX	$.00784
Emery, A. I. E. E., for 7,090 hours, table XXI	.00617
Emery, *Eng. Magazine*, 3,080 hours	.00856
Webber, 650 H. P., 3,080 hours, table XXIV	.00720
Webber, 1,050 H. P., 3,080 hours, table XXIII	.00646
Hale, 2,985 hours, table XXV	.00557
Main, 3,080 hours, table XXVIII	.00687
Foster, average, 3,080 hours, table XV	.00824
Average of all	$.00705

CONCLUSIONS.

The writer has attempted in various ways, to group the foregoing tables for comparison with each other, but gave up the attempt as hopeless, with the exception of the class of large compound condensing engines used so generally in the large mills of the east; table XXIX shows the comparison of costs per hour as developed in the various tables in this class of engine, and although as previously stated by the writer, the average is hardly to be depended on for use in careful estimates, an average has been computed of the costs by different estimaters and is seen to be $.00705 per horse-power per hour. The especial point the writer desires to bring out, is the widely varying costs here shown; take for instance Mr. Hale's of $.00557 as compared

TABLE XXX.

Comparison of Cost of Power per Annum. By Various Types of Engines. Coal at $3.00 per 2,000 Lbs.

Type of Engine and Number of Plant.		Power Developed.	Cost per H. P. per Annum.			
			Operating Expense.	Fixed Charge.	3,080 Hours.	8,736 Hours.
Slow Speed Non-Condensing	1	297	$71.92	$7.81	....	$79.73
" " "	3	59	117.55	33.82	....	151.37
" " "	5	22	88.24	17.80	106.04	....
" " "	8	129	21.31	9.41	30.72	....
" " "	16	187	18.20	4.47	22.67	....
" " "	12	273	85.00	8.83	94.53	....
" " Emery	B	556	23.66	8.05	32.61	....
" " "	B	556	84.91	8.96	....	93.87
" " Main.....XXVIII.		1,000	19.37	6.49	25.86	....
High Speed Non-Condensing	14	21	157.86	28.42	....	186.28
" " "	4	18	175.23	25.40	200.63	....
" " "	15	33	25.38	5.83	31.21	....
" " "	13	53	64.54	29.92	94.46	....
" " Emery Eng. Mag.		70	73.15	6.00	79.16	....
" " " " "		75	36.50	6.50	43.0	....
" " " " "		542	26.84	8.62	35.46	....
" " " " "		542	74.02	8.82	....	82.64
Combination, Slow Comp. Cond. High Speed Non-Cond.	6	70	137.79	20.76	....	158.55
Combination, Slow Speed Comp. Cond. and Dbl. Cond.	19	2,422	14.17	6.73	20.90	....
	20	1,920	16.33	6.63	22.96	....
Compound High Sped Non-Cond. Emery	C	542	22.21	8 01	30.22	....
" " " " "	C	542	60.88	8.02	....	68.90
Compound High Speed Condensing. Emery	G	542	18.03	7.57	25.60	....
" " " " "	G	542	49.76	7.56	....	57.32
Triple Comp. High Speed Non-Cond. Emery.	D	542	20.73	8.82	29.57	....
" " " " "	D	542	57.12	8.80	....	65.92
Triple Comp. High Speed Condensing. "	I	542	25.93	8.00	24.00	....
" " " " "	I	542	43.98	8.00	....	52.00
Slow Speed Condensing	9	911	68.87	7.83	....	76.75
" " Emery	F	556	17.53	7.81	25.34	....
" " "	F	556	48.27	7.81	....	56.08
" " " Main.....XXVIII.		1,000	16.82	6.36	23.18	....
High Speed Condensing. Emery	E	542	19.33	7.36	26.75	....
" " " "	E	542	53.44	7.36	....	60.80
" " " Eng. Mag.		130	26.65	6.00	32.65	....
Slow Speed Compound Condensing	7	2,346	27.75	9.42	37.17	....
" " " "	18	926	13.77	8.77	22.54	....
" " " "	21	2,279	22.75	6.23	28.98	....
" " " "	22	1,011	16.08	7.74	23.82	....
" " " Emery	H	556	16.18	7 93	24.11	....
" " " "	H	556	44.50	7.94	....	52.44
" " " Emery Eng. Mag.		250	19.96	6.40	26.36	....
" " " Webber....XXIII.		1,050	13.31	6.62	19 93	....
" " " " ....XXIV.		650	25.68	6.78	32.46	....
" " " Hale.....XXV.		....	10.75	6.21	16.96	....
" " " Main.....XXVIII.		1,000	13.40	6.36	19.76	....
Slow Speed Triple Comp. Condensing	17	1,173	9.73	8.50	15.29	....
" " " " Emery	J	556	14.80	8.93	23.73	....
" " " " "	J	556	40.82	8.95	....	49.77
" " " " "	L	556	13.14	9.43	22.57	....
" " " " "	L	556	36.27	9.42	....	45.69
" " " " Eng. Mag.		500	15.19	7.20	22.39	....
Water Works Pumps, Compound Cond.	9	1,382	39.86	29.41	....	69.27
" " " "	10	37	165.30	96.70	....	261.00
" " " "	11	42	120.05	63 30	....	183 85
" " " Triple "	XVI	560	47.30	11.64	....	58.94

with Dr. Emery's of $.00856 or the writer's of $.00824, the two last are seen to exceed the first by about 50 per cent, a variation which the writer argues does not permit of stating average costs for general use. And finally, in order that the report may be of more practical value, the results have in table xxx been assembled and reduced to cost per horse-power per annum, for ten hours per day for 308 days, and for 24 hours per day for 365 days.

The first column gives the type of engines, with the number of the plant from the tables; next the amount of power developed, as showing the size of the plant; then operating and fixed expense; and in the last two columns, the total cost per annum for 3,080 hours and 8,760 hours.

This table allows a direct comparison of different plants, and different authorities.

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